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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

94-34860

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AN INVESTIGATION INTO THE LONG-TERM IMPACT OF THE CALIBRATION OF SOFTWARE ESTIMATION MODELS USING RAW HISTORICAL DATA

by

Daryl Allen Shadle

September, 1994

Thesis Advisor Tarek Abdel-Hamid

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704

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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September 1994	3. REPORT TYPE AND DATES COVERED Master's Thesis
4. TITLE AND SUBTITLE AN INVESTIGATION INTO THE LONG TERM IMPACT OF THE CALIBRATION OF SOFTWARE ESTIMATION MODELS USING RAW HISTORICAL DATA (U)		5. FUNDING NUMBERS
6. AUTHOR(S) Shadle, Daryl A		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government		
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited		12b. DISTRIBUTION CODE A

13. ABSTRACT *(maximum 200 words)*

The benefit of software cost estimation is universally recognized as one of the cornerstones of effective software project management and control. Despite the advances of computer-based estimation tools, their accuracy remains largely inadequate, and their utility among software development practitioners is limited. Consequently, the optimal estimation of software cost remains an elusive goal of most project managers. Central to this issue is the nature of the data on completed software projects that are incorporated into the organization's database of historical project results. This information forms the basis for both future project estimation and ex-post-facto assessment of estimation models. Actual project results are typically the data of choice for both the calibration and evaluation processes, despite the fact that these raw values disregard project inefficiencies such as initial size underestimation. This thesis challenges the notion that historical project results represent the preferred and most reliable benchmarks for future estimation purposes. Computer-based simulation is used to test a proposed strategy which capitalizes on an organization's learning experiences by neutralizing the cost excess caused by the initial undersizing, and that derives a posterior set of *normalized* effort and schedule estimation benchmarks. Analysis of the results indicates that normalization of the data leads to significantly improved project productivity, more optimal cost estimates, and provides the organization with increased potential for future cost savings.

14. SUBJECT TERMS Software Estimation, Software Development, Calibration			15. NUMBER OF PAGES 140
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
September 1994

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ABSTRACT

The benefit of software cost estimation is universally recognized as one of the cornerstones of effective software project management and control. Despite the advances of computer-based estimation tools, their accuracy remains largely inadequate, and their utility among software development practitioners is limited. Consequently, the optimal estimation of software cost remains an elusive goal of most project managers. Central to this issue is the nature of the data on completed software projects that are incorporated into the organization's database of historical project results. This information forms the basis for both future project estimation and ex-post-facto assessment of estimation models. Actual project results are typically the data of choice for both the calibration and evaluation processes, despite the fact that these raw values disregard project inefficiencies such as initial size underestimation. This thesis challenges the notion that historical project results represent the preferred and most reliable benchmarks for future estimation purposes. Computer-based simulation is used to test a proposed strategy which capitalizes on an organization's learning experiences by neutralizing the cost excess caused by the initial undersizing, and that derives a posterior set of *normalized* effort and schedule estimation benchmarks. Analysis of the results indicates that normalization of the data leads to significantly improved project productivity, more optimal cost estimates, and provides the organization with increased potential for future cost savings

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I. INTRODUCTION

A. BACKGROUND

The benefit of reliable software cost estimation is recognized as one of the cornerstones of effective software project management and control (Boehm, 1981, p.30). Nevertheless, accurate estimation of software development costs remains an elusive goal of most project managers, despite the proliferation of software engineering economic analysis techniques and the availability of computer-based software project management tools (Abdel-Hamid, 1990, p.71).

Software development has traditionally been viewed as a discrete set of software development life cycle (SDLC) phases, when in fact, research findings point to a dynamic environment characterized by continuous changes over time (Goddard Space Flight Center, 1990). Consequently, problems inherent with the estimation process itself, normally positioned at the beginning of the SDLC, have generally limited the utility of estimation tools based on this traditional view of software development.

Without the benefit of full knowledge of a project's ultimate scope and definition at the time of initial cost estimation, an estimation model must possess the capability to respond to influencing factors which unfold as the project progresses through the SDLC. Abdel-Hamid states that "...estimation should be a *continuous* process enhanced through constant updates of feedback data collected from project monitoring and control activities...." He argues that continuous estimation models must support the full range of estimation activities regularly encountered in the SDLC; adaptive (accommodate new organizational realities), corrective (correct initial faulty assumptions) and perfective (post-mortems to perfect project statistics). In so doing, it is imperative that the model also possess the capability to capture management-system dynamics -- project managers' reactions to real-world events *as they unfold.* (Abdel-Hamid, 1993. pp. 20-21)

Despite the improvements realized with the introduction of genuine continuous estimation models, their accuracy remains largely inadequate. Central to this issue is the nature of the data on completed software projects that are incorporated into the organization's database of historical project results. This archived information subsequently forms the basis for both future project estimation and ex-post-facto evaluation of software cost estimation models. Quite simply, this data is used to produce the organization's "best guess" of what a project of similar size and scope *should* require, in terms of development effort and schedule, if encountered in the future. In addition, it is these data values upon which estimation tool calibration, or fine-tuning to produce more accurate estimates which reflect the organization's unique software development environment, is based.

Raw project values, which represent actual results, are the conventional "data of choice" for both the estimation and calibration processes. While raw data, indeed, reflect actual results, they may certainly not reflect *optimum* results, particularly in the case of a problematic project. Inefficiencies such as initial size underestimation, plague many, if not all software development projects, and are manifested in varying degrees of cost overruns and schedule slippages. As such, direct incorporation of raw values into the historical database tends to discount the impact of these inefficiencies on project results. Instead, it merely archives this flawed information for future (mis)application, and perpetuates the cycle of inefficiency and imprecise estimation.

In response, Abdel-Hamid has proposed a strategy which "...capitalizes on an organization's learning experiences, by wringing out the cost excess caused by the initial undersizing and that derives a posterior set of *normalized* cost and schedule estimation benchmarks." (Abdel-Hamid, 1993, p. 28) These normalized values are representative of a perfectly-sized software project, and consequently should provide the organization with a more efficient benchmark for future project estimation and planning, and in retrospect, evaluating how well project resources were used.

B. PURPOSE OF RESEARCH

This research challenges the notion that raw historical values represent the preferred benchmark for calibrating software cost estimation models. Computer-based simulation is used to model the behavior of a number of synthetic project profiles to test the assumptions of both the conventional and normalized strategies for software estimation model calibration. Various experimental conditions are imposed on subsequent experiments to compare project results and identify causal relationships in an effort to substantiate the research claims.

C. THE RESEARCH QUESTION

The primary research question of this thesis is to determine if there is long-term benefit in using normalized software project cost values vice raw historical data as the benchmark for calibrating software estimation models.

D. SCOPE OF RESEARCH

The scope of this research includes the design, execution and analysis of a computer-simulated, multiple-project experiment, and comparing the results of two competing software estimation calibration strategies, in order to answer the research question. Its scope does not extend beyond the research laboratory, and there are no immediate plans for replicating this experiment in a real-world environment.

E. THESIS ORGANIZATION

Chapter II offers a statement of the experiment's objectives and a comprehensive description of the experimentation tools, to include the COnstructive COst MOdel of Software Cost Estimation (COCOMO) and the System Dynamics (SD) Model of Software Project Development. In addition, Chapter II presents the experimental design, where the hypothetical projects, project profiles and influencing factors and assumptions are defined in detail. A key element of Chapter II is a discussion of the competing software estimation model calibration strategies which form the basis of this research. Chapter III describes the experimental setting and related tasks, and elaborates on exercise organization, methodology and conduct. In addition, the dependent measures which represent key exercise metrics, are defined as they relate to analyzing and comparing exercise results.

Chapter IV presents the results of the various experiments and offers insight and analysis of the research findings. Chapter V summarizes the findings of the previous chapters, discusses the implications of this study, and proposes related opportunities and directions for future research.

II. METHOD AND PREPARATION

A. EXPERIMENTAL OBJECTIVE

This experiment will use a system dynamics model of software development to simulate the development of a set of 30 projects in a software organization, conducted iy over an approximate 12-year period. The simulated results will be incorporated into an organizational data base and used as the basis for both subsequent project estimation and calibration of the estimation tool. Two scenarios will be evaluated: the conventional method of calibration using raw historical data and an alternative calibration method using "normalized" metrics.

B. EXPERIMENTATION TOOLS

1. Constructive Cost Model (COCOMO)

The COnstructive COst MOdel, or COCOMO, was developed by Barry Boehm, and is a widely-accepted algorithmic model which is used to determine initial software development effort and schedule estimates. As a result of model refinement since its introduction, three model versions and three software development modes have evolved. The three versions include Basic, Intermediate and Detailed COCOMO, each of increasing detail and accuracy. Organic, Semidetached, and Embedded software development modes have been defined to accommodate the broad spectrum of project size, specificity, and risk encountered in the software development environment.

Basic COCOMO is the simplest version of the model, and is effective for rough order of magnitude estimates of software cost. However, Boehm cautions, "... its accuracy is necessarily limited because of its lack of factors to account for differences in hardware constraints, personnel quality and experience, use of modern tools and techniques, and other project attributes known to have a significant influence on software costs...." (Boehm, 1981, p. 58) With Basic COCOMO, estimates of effort are generated using only a single predictor variable, namely the number of delivered source instructions (DSI) developed by the project.

Intermediate COCOMO improves upon the Basic version by incorporating an additional 15 predictor variables, or cost driver attributes, which are carefully identified, weighted and introduced in order to offset much of the cost variation found in Basic COCOMO. The 15 cost drivers are subdivided into four categories: software product attributes, computer attributes, personnel attributes, and project attributes. Each cost driver has an associated effort multiplier which is applied to the nominal development effort to obtain a more accurate estimate. Boehm contends that the level of accuracy achieved with Intermediate COCOMO "... is representative of the current state of the art in software cost models." (Boehm, 1984, p. 16)

Detailed COCOMO provides the highest level of estimation accuracy by providing even more detail as model input. This is accomplished by employing a three-level hierarchical decomposition of the software product whose cost is to be estimated. In addition, phase-sensitive effort multipliers are used to accurately reflect the effect of the cost drivers on the phase distribution of effort. (Boehm, 1981, pp. 347-348)

The three COCOMO modes of software development were defined as a result of research findings suggesting that software products of the same size often require varying degrees of effort and development time. Consequently, each of the COCOMO software development mode's effort and schedule equations will yield significantly different cost estimates. Hence, precise identification of the applicable mode, by means of its distinguishing features, is critical in order to prevent estimation inaccuracies.

The organic mode represents projects that are relatively small in size, developed by small software teams in a generally stable development environment. Experience levels are high, while schedule and performance pressures are generally lower.

The semidetached mode represents the middle ground between the organic and embedded modes. Flexibility of approach is a trademark of the semidetached mode, as intermediate levels of project characteristics and a blend of organic and embedded mode characteristics may be encountered in the same project.

Finally, the embedded mode represents a project that must operate within tight constraints. Requirements and interface specifications are generally inflexible, and can dictate a considerable need for innovative architectures, algorithms or functionalities. (Boehm, 1981, p.81)

In this series of experiments, the Basic COCOMO version will be utilized as the software estimation model. While Intermediate COCOMO estimates have proven clearly superior, the rudimentary nature of the Basic COCOMO (only size input - no cost driver attributes) facilitates evaluation of model characteristics in conjunction with the SD simulator. Likewise, the organic software development mode complements the choice of Basic COCOMO, and assumes a stable baseline software development environment in which the experiments can be conducted.

2. A Dynamic Simulation Model of Software Development

Research has underscored the impracticalities of controlled experimentation in the software engineering field as being excessively costly and time-consuming (Myers, 1978). Simulation modeling provides a flexible and ideal environment in which competing assumptions and conditions may be tested. Unlike real systems, the effects of variable manipulation on internal system interactions can be isolated and more carefully studied. Consequently, for purposes of this experiment, simulation modeling was chosen as the experimental method by which the research question would be answered.

The System Dynamics (SD) Model of Software Project Development, by Abdel-Hamid and Madnick, is a comprehensive, highly-detailed, quantitative simulation model which captures management-system dynamics and provides a continuous simulation capability. Based on the feedback principles of system dynamics, the model focuses on four interconnected subsystems, which integrate managerial decision-making activities (e.g., scheduling, productivity, and staffing) with the physical production of the software product (e.g., design, coding, reviewing, and testing). The four subsystems are human resource management, software production, controlling, and planning. (Abdel-Hamid, 1993, p. 24)

The purpose of the SD simulator is to serve as a laboratory vehicle for conducting experimentation into the dynamics of software development. As such, it provides a much-needed means by which the managerial side of the software development process might be more carefully examined and, hopefully, better understood. By design, the model does not deliver point predictions, but rather seeks to provide a general understanding of the nature of the dynamic behavior of a project. An important functionality of the model is the ability to perform sensitivity analysis, or "what-if" experiments, in order to develop a more complete understanding of the interrelationships of software development variables and identification of causal relationships.

The model has been designed for use on medium sized, organic type software projects (i.e., projects that are 10,000 to 250,000 lines of code and conducted in familiar, in-house development environments) (Stephan, 1992, p. 13). For a detailed discussion of the model's actual structure, formulation and validation, see Abdel-Hamid and Madnick (1989 and 1991).

C. EXPERIMENTAL DESIGN

1. Definition of Experimental Projects

Five hypothetical software development projects, of varying representative sizes, were initially defined and serialized as projects one through five. Their size was established in terms of thousands of delivered source instructions (KDSI) to match both the COCOMO and SD simulator input parameters. Table 1 presents project serials and their respective sizes, which remain fixed throughout all experiments.

Project Serial	Actual Size (KDSI)
1	40
2	50
3	60
4	70
5	80

Table 1. Experimental Projects and Sizes

2. Underestimation of Project Size

Boehm states, "The software undersizing problem is our most critical road block to accurate software cost estimation." He cites three main reasons for this perplexing phenomenon. First, people's optimistic and accommodating nature drive them to say what others want to hear. High estimates are fuel for confrontation, whereas everyone is happy with small, easy software. The second reason involves incomplete recall of the large amount of support software that must be developed as part of a project -- there is generally a stronger recollection of the size and effort required for the much smaller, but *more visible, operational* software. The third reason is related to the incomplete recall issue. Unfamiliarity with the full scope of the software project causes people to overlook the more obscure software products (and obscure portions of each product) which need to be developed. There are no quick fixes to the pervasive undersizing problem other than to understand the sources of the problem, and apply that understanding to software sizing activities. (Boehm, 1981, pp. 320-323)

A study of the impact of undersizing on software estimation forms the focus of much of this experiment. Consequently, underestimation levels, expressed as a percentage of actual project size, are applied to the individual project serials in accordance with the experimental project profile, which is defined in a subsequent section of this report. Underestimation levels are defined and presented in Table 2.

Level	Underestimation (%)
1	10
2	20
3	30
4	40
5	50

Table 2. Project Size Underestimation Levels

Undersizing has a direct effect on both *the software cost model* (COCOMO) and the simulation model (SD simulator) results. Quite simply, a too-small sizing estimate invariably results in a too-small cost estimate. For example, a 50 KDSI project, undersized by 20 percent, results in a Basic COCOMO estimation identical to that of an accurately-sized 40 KDSI project.

3. Development of Project Profiles

The experiment seeks to model and analyze the software development activities of a hypothetical organization over time. In developing a project profile for the organization, particular attention was paid to a number of conditions within the organization that would accomplish exercise objectives, while maintaining a reasonable degree of realism with respect to the functioning of an actual software development organization.

a. Project Teams

Five hypothetical software development teams are constructively assembled. As teams, they will be assigned to one of the project serials -- one team for each project serial. There was no consideration given to team make-up in assembling the teams. Although disregard for the effects of personnel attributes on team performance represents an exercise artificiality, the assumption of essentially "homogeneous" project teams facilitates unbiased interpretation of the exercise results.

b. Project Cycles

In order to investigate the long-term impact of calibration strategies on software cost estimation, follow-on projects to the five project serials already defined is required. Consequently, the concept of a project cycle is introduced. A project cycle is defined as that period of time required for each of the five individual project serials to be completed. The first iteration of this scheme is referred to as "Project Cycle One", whereas subsequent iterations are labeled "Project Cycle Two", "Project Cycle Three", etc. For purposes of this experiment, organizational software development activities will span six project cycles.

c. Initial Project Team Assignments

With teams assembled, and projects and project cycles defined, the next step is to determine a strategy for project assignment. Here the assumption is that all five software development teams will commence work on the five project serials concurrently, at time zero. For simplicity, and to provide a convenient project profile starting point, assignment of projects in project cycle one matches team one with project one, team two with project two, etc.. Table 3 outlines cycle one project assignments.

Project Cycle One	
Project Team	Project Assignment
One	1
Two	2
Three	3
Four	4
Five	5

Table 3. Cycle One: Team and Project Assignments

d. Allocation of Undersizing Factors

In order to examine the effects of undersizing on projects of varying size, the previously-defined size underestimation levels (Table 2) must be allocated in a random manner across all projects. For project cycle one, this was accomplished by using a table of numbers generated by a random process. Table 4 is such a table and is used in the experiment. By arbitrarily selecting the intersection of any row and column as the starting point, a list of five numbers is systematically drawn by moving either to the left or right, or upward or downward from this starting point until one of the underestimation level values is encountered. This number is recorded in the list, and the movement continues until a second number within the allowable range (one through five) is encountered. After this second value is recorded in the list, the process repeats three more times until the randomized list of five numbers is complete. For example, underestimation levels are allocated for project cycle one by choosing row 5, column 13

ROW	Column Number																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	2	7	8	9	4	0	7	2	3	2	5	4	2	6	7	1	6	8	5	9	1	3	5	4	0	3	6	6	7	6	5
2	2	2	6	0	4	1	7	7	3	8	7	3	6	7	9	4	2	1	3	8	9	0	3	4	9	0	2	6	3	0	9
3	9	1	6	6	3	9	4	9	1	0	5	1	5	2	2	7	5	2	5	3	4	1	3	9	5	8	1	3	8	2	9
4	7	0	5	5	9	2	7	5	7	8	0	8	8	5	0	6	0	5	9	0	5	7	4	5	2	0	6	1	6	4	2
5	4	7	3	6	6	3	9	8	2	1	7	9	7	6	4	2	4	9	6	0	3	6	3	5	3	9	9	1	8	5	1
6	8	2	0	2	8	7	7	6	0	2	2	3	1	1	1	6	4	8	5	2	2	3	4	2	2	6	5	2	2	4	9
7	0	8	7	5	3	3	6	4	2	6	8	3	1	6	5	0	0	5	5	7	8	1	0	1	2	9	1	4	3	4	7
8	9	4	1	9	0	8	4	6	6	8	6	3	3	2	2	3	7	4	7	5	1	5	7	6	3	7	9	4	5	5	3
9	5	0	0	6	7	4	0	0	0	1	9	5	9	9	1	8	1	4	7	4	9	8	7	2	4	3	0	8	6	4	2
10	1	9	5	4	1	5	2	6	2	9	4	1	1	5	8	4	4	4	6	1	8	7	8	6	4	8	7	4	4	0	5
11	5	6	4	4	1	8	7	2	8	3	6	1	5	9	8	6	2	2	9	1	9	0	4	8	1	0	1	3	5	3	4
12	7	9	2	5	1	9	7	9	3	1	8	6	8	7	7	6	6	5	0	3	8	1	1	2	4	7	8	9	1	7	5
13	3	3	3	5	9	5	1	4	0	8	2	5	6	3	5	4	6	5	7	2	6	7	8	9	9	9	8	0	9	1	5
14	1	9	0	4	0	0	9	9	5	7	4	1	5	9	4	7	6	4	8	2	6	4	4	1	8	8	1	5	4	3	8
15	5	4	4	7	2	0	3	7	9	1	0	9	6	2	9	7	4	7	6	1	1	6	1	2	2	9	5	8	4	4	8
16	2	9	8	2	5	5	9	3	2	0	4	9	0	6	4	4	2	1	5	7	3	6	5	5	4	5	7	9	6	6	4
17	9	7	6	2	6	7	7	3	3	3	1	7	5	0	9	6	1	1	3	9	2	1	1	0	0	1	3	7	7	3	7
18	5	8	2	4	3	3	0	8	5	3	5	7	5	8	3	5	9	3	4	5	4	6	3	9	2	7	1	1	4	9	1
19	4	3	4	9	5	0	3	6	2	9	7	4	6	2	5	6	9	8	3	6	1	4	0	3	5	9	7	1	8	0	6

Table 4. Table of Random Numbers. After Ref. (Roscoe, 1975, p. 410)

(Table 4) as the starting point and moving across the row to the right. The following randomized list is generated: 4 - 2 - 3 - 5 - 1. These numerical values, corresponding to underestimation levels, are allocated to cycle one projects as shown in Table 5.

Project Cycle One	
Project #	Undersizing Level
1	4
2	2
3	3
4	5
5	1

Table 5. Cycle One: Projects and Undersizing Levels

For project cycles two through six, undersizing levels are allocated in accordance with the Latin Square Design (Daniel and Terrell, 1975, pp. 209-215). Once the cycle-one undersizing levels are determined and allocated to the five project serials in ascending project-size order, Latin Square imposes a one-position downward shift of row values to produce the undersizing allocation for cycle two. The procedure is repeated through the six project cycles, which results in cycle-six undersizing levels identical to those in cycle one. Table 6 presents the undersizing allocation for all projects across all project cycles. This allocation plan is fixed, and is used for all experiments where software size underestimation is assumed.

Project #	KDSI	Project Cycle					
		1	2	3	4	5	6
		Underestimation Level					
1	40	4	1	5	3	2	4
2	50	2	4	1	5	3	2
3	60	3	2	4	1	5	3
4	70	5	3	2	4	1	5
5	80	1	5	3	2	4	1

Table 6. Project Undersizing Allocation

e. Project Team Assignments in Cycles Two through Six

In developing the project profile, it was decided that when a project team completed their assigned project in cycle one, they would immediately be assigned a new project and commence work in cycle two. That is, the team that finishes their cycle-one project first, is assigned the first available project in cycle two. The second team to finish cycle one gets the next available project in cycle two, and so on, until all five teams "arrive" in project cycle two. Subsequent project assignments are determined in the same manner through project cycle five.

The sequence of next-available projects for project cycles two through five are randomly assigned. Their project assignment orders are determined by employing the same randomization techniques described in the previous section, but with different starting coordinates and directions of movement for generating the randomized list for each cycle.

To facilitate comparative analysis of results with cycle one projects, cycle six team assignments replicate their initial project assignments. Table 7 defines the next-available project scheme for all six project cycles.

Order of Project Completion in Present Cycle	Project Cycle				
	2	3	4	5	6
	Next-Avalibale Project				
1	2	3	1	5	1
2	1	4	4	4	2
3	3	1	5	2	3
4	5	5	3	1	4
5	4	2	2	3	5

Table 7. Next-Available Project Schedule

f. Finalized Experimental Project Profile

The final project profile, which incorporates next-available project assignments and their respective undersizing levels, is presented in Table 8. All experiments follow this project-order and undersizing arrangement (when applicable). While project team assignments in other than the initial project cycle may vary under different exercise scenarios, depending on calculated total development schedule values, the follow-on project order and underestimation levels of Table 8 remain fixed in all cases. Figure 1 displays a representative Total Development Schedule for all five project teams over six project cycles, applying the experimental project profile.

Team	Project Cycle One		Project Cycle Two		Project Cycle Three		Project Cycle Four		Project Cycle Five		Project Cycle Six	
	Project Number	Undersize Level	Project Number	Undersize Level	Project Number	Undersize Level	Project Number	Undersize Level	Project Number	Undersize Level	Project Number	Undersize Level
1	1	4	2	4	4	2	4	4	5	4	1	4
2	2	2	1	1	3	4	1	3	4	1	2	2
3	3	3	3	2	1	5	5	2	2	3	3	3
4	4	5	5	5	2	1	2	5	3	5	4	5
5	5	1	4	3	5	3	3	1	1	2	5	1

Table 8. Final Experimental Project Profile

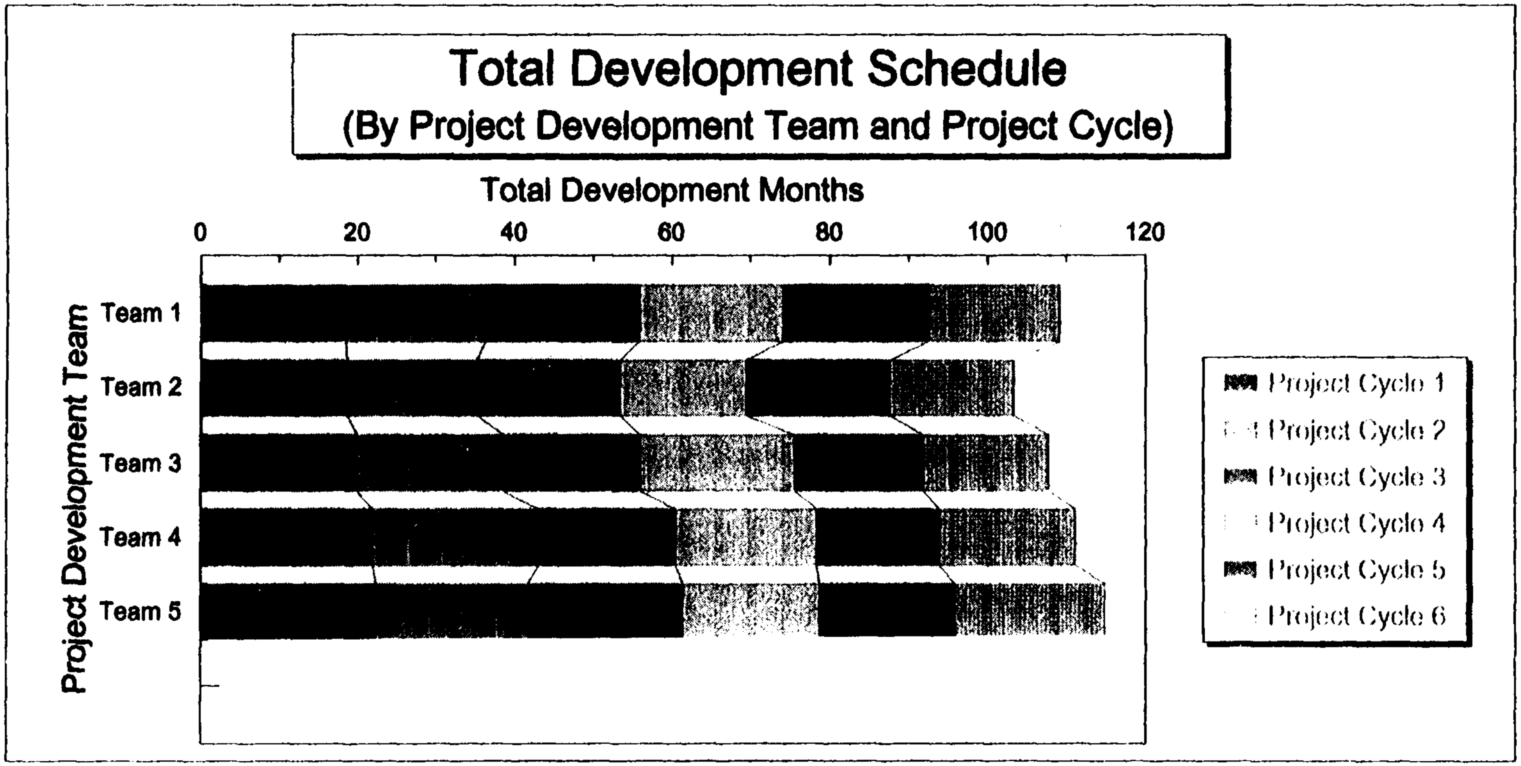

Figure 1. Total Development Schedule

4. Learning

The effects of "learning" on software estimation and productivity are an important element of this research. It is reasonable to assume that the effect of experience and increases in project familiarity should be reflected in higher productivity. In an attempt to model the rate of learning improvement, a plan involving the incremental increase of a related SD simulator input variable was developed.

In the SD model, nominal productivity is defined as one task per man-day. A task is any arbitrary unit by which a software project may be measured (Abdel-Hamid and Madnick, 1991, p. 80). In our experimentation vehicle, a "task" is defined in terms of a discrete number of Delivered Source Instructions, hence the SD input parameter *Delivered Source Instructions per Task* (DSIPTK). Consequently, an appropriate increase in DSIPTK over the nominal simulator value as projects are developed, can effectively model the 'learning curve' effect we are searching for.

For purposes of this experiment, we assume that "learning" is reflected in a 10-percent annual increase in DSIPTK. While total project development schedules obviously vary, an 18 to 24-month timeframe represents a reasonable estimate of duration for the hypothetical projects as defined. Consequently, a 20-percent increase in DSIPTK was applied to each project cycle beginning with project cycle two. This value is consistent with research findings and industry experiences (Aron, 1976). Hence, the learning scenario is defined as an incremental increase of DSIPTK from 100 percent of nominal value to 200 percent of the nominal SD simulator value over the six project cycles. Table 9 demonstrates how the learning scenario was applied.

Project Cycle	DSIPTK: Percent of Nominal Value
1	100%
2	120%
3	140%
4	160%
5	180%
6	200%

Table 9. Learning Scenario

5. Conventional COCOMO Calibration Strategy

"Calibration" is one method by which an organization may tailor a software cost-estimation tool to more accurately reflect its unique software development experiences. Boehm asserts that calibration of COCOMO may be necessary, for various reasons, to provide an organization with the best estimation accuracy "fit". He offers a technique for calibrating the constant term in the COCOMO nominal effort equation, and this procedure will be replicated as part of the experiment, and throughout the thesis will be referred to as the "conventional" calibration strategy.

Having selected the Basic COCOMO model and the organic mode as the most appropriate software development mode for our hypothetical organization, the calibration methodology is straightforward. Table 10 presents the Basic COCOMO effort and schedule equations for the organic mode. A few terms require definition in understanding these equations. Under the *Effort* column, "MM" refers to the number of man-months estimated for the software development phase. One man-month is equal to 152 hours of working time. Under *Schedule*, "TDEV" is the number of estimated months for software development.

Mode	Effort	Schedule
Organic	$MM = 2.4\,(KDSI)^{1.05}$	$TDEV = 2.5\,(MM)^{0.38}$

Table 10. Basic COCOMO Effort and Schedule Equations (Organic Mode)

The constant term in the effort equation above (2.4) is the value which is calibrated. Because of the absence of cost driver attributes in Basic COCOMO, the optimal coefficient may be calculated using the following equation:

$$\widetilde{C} = \frac{\sum_{i=1}^{n} MM_i(actual)*Q_i}{\sum_{i=1}^{n} (Q_i)^2} \tag{2.1}$$

In the above equation, MM_i(actual) is the actual development effort of the software project. In our experiment, this value is generated by the SD simulator, based on input values which include the Basic COCOMO effort and schedule estimates. The variable Q_i for organic mode re-calibration, is defined as the actual size of the project (KDSI(actual)) raised to the power 1.05. Having determined these values, the calibration process continues by multiplying MM_i(actual) times Q_i for each project. The summation of this product is determined for the number of projects being factored in to the re-calibration (n). This value forms the numerator of the re-calibration equation. The denominator is calculated by first squaring each Q_i value, then summing these values. The resultant coefficient represents the derived optimal constant term and replaces the organic

COCOMO coefficient value of 2.4 for estimation of the next series of (n) projects. Chapter IV provides additional clarification of the calibration methodology using exercise data.

6. Alternative "Normalization" Calibration Strategy

Boehm commented on a comparative analysis of software cost models, that "...Not too surprisingly, the best results were generally obtained using models with calibration coefficients against data sets with few points...." (Boehm, 1984, p. 18). A similar analysis of the validity of the assumptions upon which calibration strategies are based, and their impact on software estimation model performance has received considerably less attention.

Basic COCOMO embraces the assumption that historical project results represent the preferred and most reliable benchmarks for future estimation purposes. This experiment challenges that notion, and seeks to validate the work of Abdel-Hamid by using the SD model as an experimental vehicle to demonstrate why this assumption is flawed (Abdel-Hamid, 1990, p. 79).

Using data from a real software project conducted by NASA, Abdel-Hamid conducted two experiments as part of SD model validation. The first experiment investigated one of two fundamental assumptions upon which conventional calibration strategies are based. That is, a project's final results are independent of its initial estimation values. His research findings indicate that different estimates do, indeed, create different projects. He reported that initial project effort and schedule estimates *significantly influence* work force level decisions, productivity, work intensity, and communication and training overheads. Clearly, acceptance of these findings leads to rejection of the convention that actual project results provide the best information for future estimation activities.

Abdel-Hamid's second experiment sought to further refute the notion that raw historical project values should be the "data of choice" for both the calibration and ex-post-facto evaluation of estimation tools. Again, using the NASA data, he reported how the initial 35-percent size underestimation lead to a corresponding underestimate of project effort and duration. He observed how learning, in the form of increased project familiarity and experience, lead to the discovery of overlooked tasks, which in turn resulted in a dramatic "staff explosion" late in the development cycle, in order to meet a rigid deadline. At this point, the representativeness of NASA's *actual* project cost as the basis for future effort estimation becomes suspect due to the problematic nature of the project. A new project of similar size and scope, but more accurately sized at the outset, and consequently more effectively staffed, should result in project costs somewhat less than the actual results of NASA's troublesome effort.

In his work, Abdel-Hamid outlines a "normalization" strategy for eliminating inefficiencies due to initial project undersizing which incorporates the capabilities of the SD simulator. Much of this research work is aimed at examining and testing this strategy against the conventional calibration strategy under a variety of conditions and scenarios.

In theory, the normalization strategy seeks to determine the extent of man-day excesses, and adjust the archived calibration/estimation values accordingly. Figure 2 diagrams both the current calibration practice and the proposed normalization strategy.

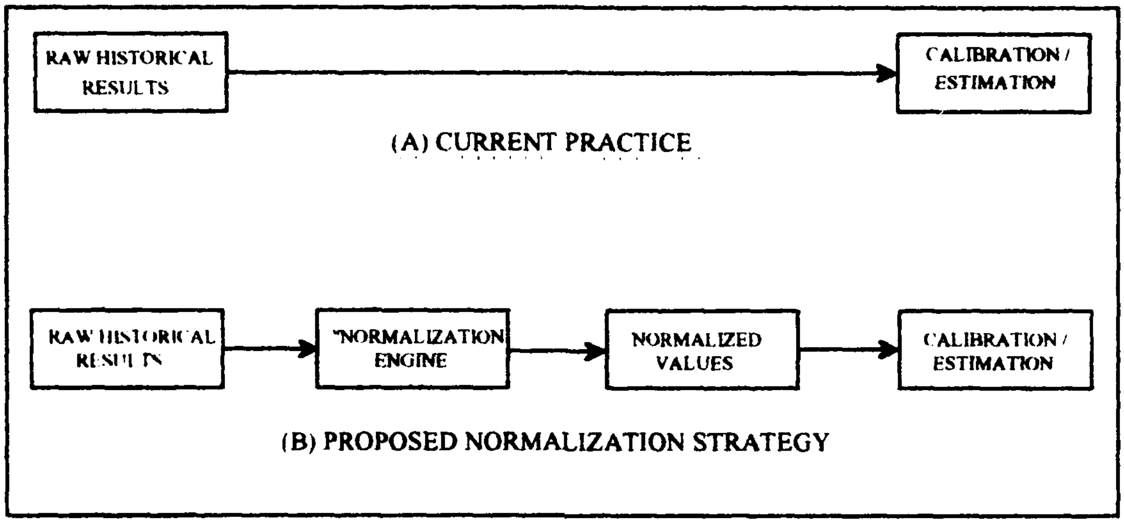

Figure 2. (a) Current Practice: (b) Proposed Normalization Strategy

To determine the normalized cost value, a project must be re-simulated with no undersizing. Optimization of cost savings is determined by repeated simulations in which actual project size and schedule inputs are fixed, while effort inputs are systematically reduced until further input reductions begin to yield higher cost outputs.

The input and output values generated during a typical normalization process are presented in Table 11. Repeated simulations in which actual project effort (MM(est)) is systematically reduced with each simulation, yields a series of actual costs (MM(act)). The shaded cell in Table 11 is the lowest numerical result generated by the SD simulator under all input conditions. This represents the project's "normalized" man-month value and reflects the optimum cost savings achievable in a perfectly-sized project. The estimated versus actual cost values of Table 11 are graphically represented in Figure 3 to further illustrate the normalization process

Cycle #1, Project #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18.5	120.9	120.6
40	18.5	115	115.3
40	18.5	110	114.6
40	18.5	105	113.4
40	18.5	100	112.7
40	18.5	95	112.6
40	18.5	90	112.7
40	18.5	85	113.3
40	18.5	80	115.4

Table 11. Normalization Values

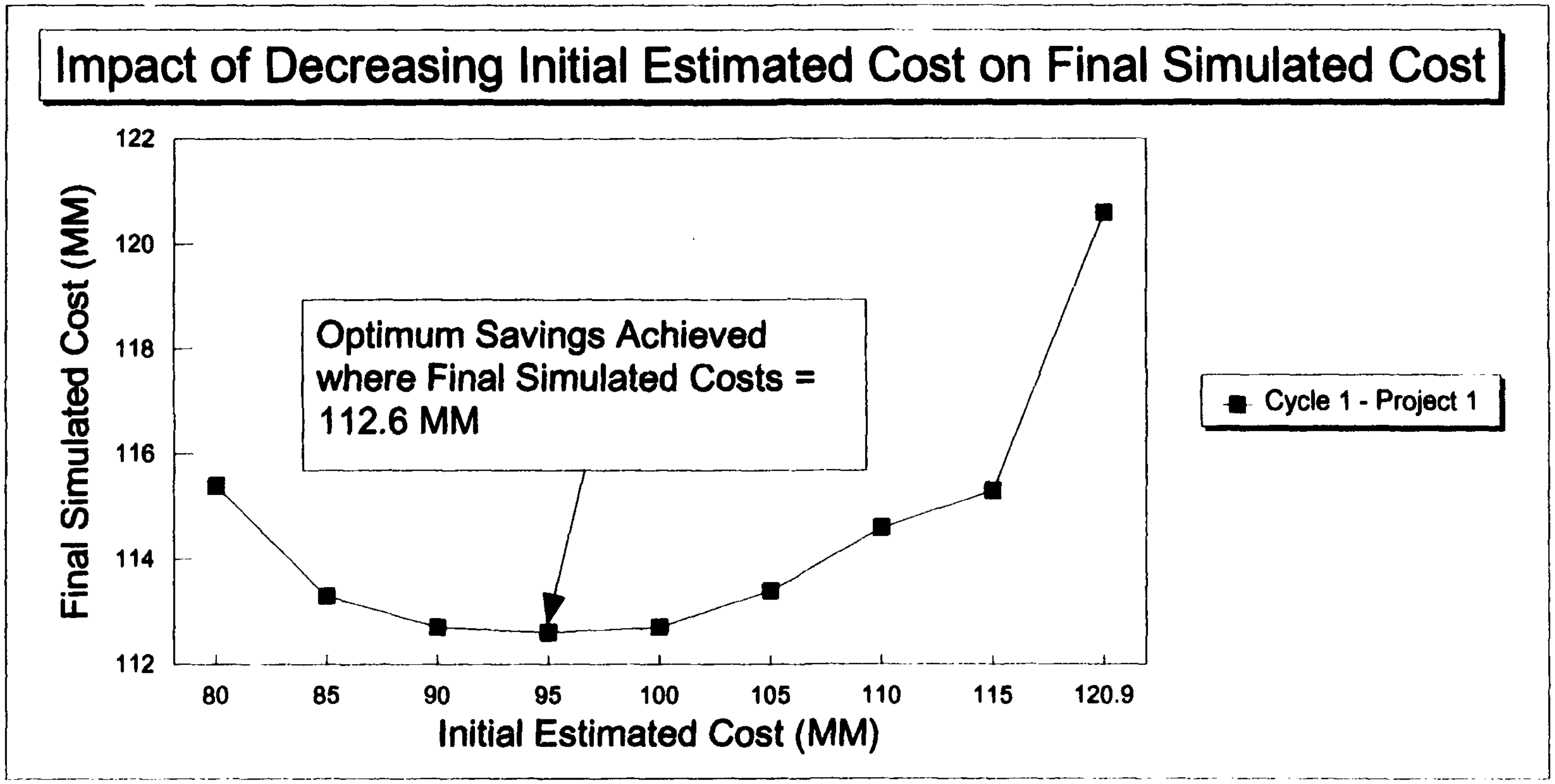

Figure 3. The Normalization Process

III. CONDUCTING THE EXPERIMENT

A. EXPERIMENTAL SETTING

All experiments involve extensive simulation modeling and cost estimation calculations. In addition, archiving requirements for a significant volume of generated data is necessary, as well as relational processing capabilities to conduct comparative analysis of the findings. These requirements were satisfied, and the experimental tasks successfully accomplished on an IBM-compatible 486-DX2/66 personal computer (PC).

The System Dynamics (SD) simulator runs in the MS-DOS environment, however the PC was configured to run the application in a window of Microsoft Windows 3.1, to facilitate transfer of information. User interface is via the keyboard. Figure 4 is the "changes" screen, where input parameters are entered to examine the various exercise scenarios. Of note, the fields routinely used in experiment simulations are found on this screen such as *DSIPTK* and *UNDEST* (first column), *TOTMM* (second column), and *TDEV1* (third column). A tailored report is also generated for each completed simulation, and provides not only a convenient presentation of simulation results, but also displays initial input parameters to permit easy verification of data entry. A copy of one such report is presented in Figure 5.

An electronic spreadsheet, specifically Lotus 1-2-3, release 4.1 for Windows, was chosen as the appropriate application for managing and presenting the experimental data. It offers advanced spreadsheet, charting, drawing, scenario and database features which

```
DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD Parameters DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD
  ADMPPS=         1.   AQADLY=        10.   ASIMDY=         80.   AVEMPT=       673.
  CTRLSW=         1.   DBSRWD=        15.   DEVPRT=         .8    DLINCT=        10.
  DSIPTK=        60.   EXHDDY=        20.   HIREDY=         40.   INUDST=         .5
  MDSWCH=         1.   MNHPXS=         3.   MSZTWD=     10.e-3    MXEXHT=        50.
  MXSCDX=      1.16    NFMDPJ=         .6   NPWPEX=          1.   NPWPNE=         .5
  PBADFX=    75.e-3        QO=         0.   RJBDSI=      40.e3    RPTDLY=        10.
  SCHCDM=         1.   SCSWCH=         1.   TARMPB=         10.    TDEV1=       12.6
  TMPRPB=       .15     TOTMM=      127.3   TRNSDY=         10.   TRPNHR=         .2
  TSAODS=        40.   TSTOVH=         1.   TSTSPD=         50.   UNDESM=         0.
  UNDEST=        .4
DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD Tables DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD
                  1          2          3          4          5          6
  TADJQA-        0.   -25.e-3       -.15       -.35      -.475        -.5
                  1          2          3          4          5          6          7
  TCONOH-        0.    15.e-3     60.e-3       .135        .24       .375        .54
                  1          2
  TDAJMD-        .5         3.
                  1          2          3          4          5          6          7
  TERMFR-        0.         0.         0.         0.     10.e-3     20.e-3     30.e-3
                  8          9         10         11
  TERMFR-    40.e-3         .1         .3         1.
                  1          2          3          4          5          6          7
  TEXABS-        0.         .2         .4        .55         .7         .8         .9
 Changes:  Arrows  Home  End  PgUp  PgDn  Values  Enter for GTC  Esc to cont
```

Figure 4. SD Simulator "CHANGES" Screen

```
INITIAL ESTIMATES:
------------------

    Project Size                                   24.0      KDSI
    Project Cost                                  127.3      Person-Months
    Project Duration                               12.6      Months


FINAL PROJECT RESULTS:
----------------------

    Actual Project Size                            40.0      KDSI
    Total Man-Months                              161.7      Man-Months
    Completion Time                                15.3      Months
```

Figure 5. Tailored Simulation Report

were extremely valuable tools in conducting, analyzing, documenting and presenting the results of the experiment.

B. RELATED EXPERIMENTAL TASKS

With a clear statement of the experimental objective, appropriate choice of experimentation vehicles, and a valid experiment design, several administrative tasks remain to facilitate conducting the experiment and handling the data. Important to this pre-execution phase is the development of a number of worksheet templates in Lotus 1-2-3. The "calculations worksheets" are of particular value -- project profile data and simulated project cost data are directly entered here. Incorporated within the calculations worksheets are numeric cell formulas and interrelationships such that upon appropriate entry of project data, key dependent values are automatically calculated. Figure 6 is an example of a calculations worksheet. A detailed explanation of the calculations worksheet's operation is presented with the research findings in Chapter IV.

In addition, a number of tailored spreadsheet tables were developed to archive, perform comparative analysis on, and display the collected data in a consolidated, readable format. Appendix B is an example of this type of tailored spreadsheet table.

C. DEPENDENT MEASURES

Answering the research question requires capturing key simulation and computational data on project performance and productivity. These values are absolutely essential to meaningful analysis and interpretation of the research findings. Each of these values is

CYCLE #1 (Raw Data, 100% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1		40	40	24				
2		50	20	40				
3		60	30	42				
4		70	50	35				
5		80	10	72				

Proj Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40			48			2304	2304			
2	50			61			3721	6025			
3	60			74			5476	11501			
4	70			87			7569	19070			
5	80			100			10000	29070			

CYCLE #2 (Raw Data, 100% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
2		50	40	30				
1		40	10	36				
3		60	20	48				
5		80	50	40				
4		70	30	49				

Proj Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
[illegible]	[illegible]			61			3721	3721			
[illegible]	[illegible]			48			2304	6025			
[illegible]	[illegible]			74			5476	11501			
5	[illegible]			100			10000	21501			
4	[illegible]			87			7569	29070			

CYCLE #3 (Raw Data, 100% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4		70	20	56				
[illegible]		60	40	36				
[illegible]		40	50	20				
2		50	10	45				
5		80	30	56				

Proj Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70			87			7569	7569			
3	60			74			5476	13045			
1	40			48			2304	15349			
2	50			61			3721	19070			
5	80			100			10000	29070			

CYCLE #4 (Raw Data, 100% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4		70	40	42				
1		40	30	28				
5		80	20	64				
2		50	50	25				
3		60	10	54				

Proj Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70			87			7569	7569			
1	40			48			2304	9873			
5	80			100			10000	19873			
2	50			61			3721	23594			
3	60			74			5476	29070			

Figure 6. Research Calculations Worksheet (Lotus 1-2-3)

described below; parenthetical text following each heading reflects the abbreviation used for this value throughout the thesis:

1. Actual Project Effort (*MM(act)*)

Actual Project Effort is one of the dependent variables generated by the SD simulator, and represents the number of actual man-months required for the software development phase of each individual project.

2. Actual Project Schedule (*TDEV(act)*)

This value is also a dependent variable generated by the SD simulator, and represents the actual number of months required for completion of the software development phase of each individual project.

3. Actual Project Productivity (*Productivity*)

Actual Project Productivity is an important metric by which competing calibration strategies are compared and evaluated. It is calculated by dividing the actual project size (KDSI(act)) by the actual project effort (MM(act)). This value is calculated ex-post-facto for each individual project. It is expressed as a decimal value, and there is an inverse relationship between actual project effort and actual project productivity.

4. Composite Cycle Productivity (*Comp Prod*)

Composite cycle productivity is a deterministic value which reflects the combined productivity of all five projects as defined in a particular project cycle. It is calculated by dividing the total actual size of all projects in the cycle (summation of KDSI(act)), by the total actual effort of all projects (summation of MM (actual)). Since the total actual size of all projects in each cycle is fixed (300 KDSI), composite productivity is driven by the value of total project effort -- the lower the total effort, the higher the composite productivity.

5. Average Staff (*Avg Staff*)

This value represents the average staffing level for each project. The accurate projection of required staff levels is a critical function in software development. Average Staff is calculated in COCOMO by dividing the actual project effort (MM(act)) by the actual project schedule (TDEV(act)).

6. Normalized Project Effort (*MM(norm)*)

Normalized Project Effort is the value resulting from the application of the normalization process, described in detail in Chapter II, to Actual Project Effort (MM(act)). Its value represents an optimal achievable level of project effort and forms the basis for calculation of the COCOMO Calibration Coefficient in the alternative calibration strategy which is examined in this experiment.

7. COCOMO Calibration Coefficient (*Coefficient*)

"Calibration" is one method by which an organization may tailor a software cost estimation tool to more accurately reflect its unique software development experiences. "Coefficient" refers to the constant term in the COCOMO nominal effort equation, and its calculated value is critical to subsequent model estimation accuracy. The central issue in the evaluation of the conventional versus the alternate (normalized) calibration strategies involves the appropriateness of the independent variable upon which the coefficient calculation is based. In the conventional calibration strategy, it is based on actual project effort (MM(act)), while the normalized calibration strategy bases its computation on normalized project effort (MM(norm)).

D. ORGANIZING THE EXPERIMENT

The experiment is conducted in four phases. Presented in this section of the report are the research objectives of the various experiments, an explanation of how each phase is organized, and a general explanation of the exercise "flow". Detailed process definitions are presented along with the experimental results and analyses in Chapter IV.

1. Phase One

The objective of this phase is to compare the simulated project cost results obtained by applying the conventional software estimation tool calibration strategy, against a similar set of cost values obtained by applying the normalized calibration strategy. Both learning and undersizing are assumed in this scenario. The project profile determines the project-set order and undersizing allocation for each of the six project cycles. The SD simulator and COCOMO equations are used to both replicate the conventional calibration strategy and test the alternative normalization strategy. Key computational values (Dependent Measures) are captured, and a comparative analysis of the two calibration strategies is offered. The data set collected in Phase One constitutes the "base case" results, against which all other scenarios are tested.

2. Phase Two

In Phases Two through Four, the experiment is structured to perform sensitivity analysis on the base case results. Different assumptions and environmental factors are examined by using the SD simulator's ability to change one input variable while holding all others constant. In each scenario, particular attention is paid to the effects of "normalization", vis-a-vis the conventional calibration strategy, on the experimental results.

The objective of Phase Two is to examine the effects of size underestimation on base case results. A new case is developed where learning is assumed, but no size underestimation. Simulated results for the same project set are calculated, applying both the conventional and normalized calibration strategies, and compared with base case findings. All other conditions are identical to those in Phase One.

3. Phase Three

The objective of Phase Three is to examine the effects of learning on base case results. A new case is developed where undersizing is assumed, but no learning. Simulated results for the same project set are calculated, applying both the conventional and normalized calibration strategies, and compared with base case findings. All other conditions are identical to those in Phases One and Two.

4. Phase Four

The objective of Phase Four is to examine the impact of overestimation and underestimation of productivity on project-set results. In this scenario, we again assume undersizing and no learning, as in the previous experiment. However, this experiment explores the effect of misrepresenting productivity as a function of how the level of effort associated with the accomplishment of a software development "task" is defined within the organization.

Central to the productivity overestimation/underestimation question is the notion of "variable task definition." Disparate definitions of the effort required to accomplish a software task may account for situations where various software development organizations require different levels of development effort to design and code projects of similar size and scope. In projects where the number of delivered source instructions is identical in each organization, the value of "task" becomes the determinant with regard to measuring effort, and hence, productivity. First, this experiment re-simulates the project set and examines the impact of underestimating productivity by a factor of 75 percent of the nominal case. Next, the project set is re-simulated, this time overestimating productivity by a factor of 125 percent of the nominal case. The results are compared to Phase Three, which models the nominal case in this scenario (undersizing, no learning, and "perfectly-represented" productivity).

IV. EXPERIMENTAL RESULTS AND ANALYSIS

A. INTRODUCTION

The SD simulation model generated raw data on the actual cost and schedule for each simulated project. The manner in which these values are applied in calibrating the COCOMO software estimation tool, and its impact on productivity and cost savings under a series of conditions are the central focus of this analysis. As such, there are four principal areas of investigation. First, the replication of a conventional software estimation tool calibration strategy using raw cost data and assuming both learning and undersizing, is compared with an alternative calibration strategy using *normalized* cost data under the same assumptions. Ne [illegible] ase-case results of phase one are compared with simulated results of a new case assuming learning but no undersizing. The third area of investigation is a comparison of the base-case results with a new case in which there is undersizing, but without learning effects. Finally, the impact of both underestimation and overestimation of productivity on the results obtained in the scenario with undersizing and without learning is examined.

B. CONVENTIONAL VS. ALTERNATIVE CALIBRATION STRATEGIES WITH LEARNING AND UNDERSIZING (BASE CASE)

1. Assumptions

a. Underestimation of Project Size

The Basic COCOMO schedule estimation model requires as its single input, a user-provided estimate of the project's size in thousands of delivered source instructions (KDSI). Consequently, an inaccurate size estimate input will result in a similarly imprecise schedule estimation output. The inclination toward project size underestimation is not uncommon throughout the software industry (Boehm, 1981, p. 320). For purposes of this experiment, size underestimation, when applied, is represented as a percentage of actual project size. Undersizing is assumed to range from 10 percent to 50 percent, in 10-percent increments, and is applied to individual project serials in accordance with the project/cycle profiles presented in Chapter II. The undersizing percentages, expressed in decimal notation, are subsequently applied as the SD simulator input parameter *UNDEST*.

b. The Effects of "Learning" on Software Estimation and Productivity

By "learning" we mean increases in productivity. This learning happens as an organization gains experience in developing its type of software and as it incorporates new software development tools. As discussed in Chapter II, we assume that "learning" is reflected in a 10-percent annual increase in the SD simulator input parameter *Delivered Source Instructions per Task* (DSIPTK). Consequently, with project schedules generally approaching two years' duration, a 20-percent increase in DSIPTK was applied to each project cycle beginning with project cycle two. Therefore, the learning scenario is defined as an incremental increase of DSIPTK from 100 percent to 200 percent of the nominal value over the six project cycles.

2. Conventional Calibration Strategy

Five synthetic project serials were simulated over six organizational project cycles, for a total of 30 simulations. Key computational values, as defined in Chapter III, were calculated and tracked throughout the experiment. They include *Actual Project Effort* (MM(actual)), *Actual Project Schedule* (TDEV(act)), *COCOMO Calibration Coefficient* (Coefficient), *Actual Project Productivity* (Productivity), *Composite Cycle Productivity* (Comp Prod), and *Average Number of Staff Required* (Avg.Staff). Appendix A presents all calculations and data used to generate these key values, which are further consolidated and summarized in Table 12.

The methodology for determining actual simulated values will be described as the process unfolds in Appendix A. In the following discussion, descriptive abbreviations in parenthesis correspond to column labels in Appendix A. For each *project serial* (Proj Serial), a *learning value* (DSIPTK (%)) is assigned. A *project size estimate* (KDSI(est)) is determined by multiplying the *actual project size* (KDSI(act)) times the *size underestimation percentage* (Under (%)). Using this *project size estimate* (KDSI(est)) as the input variable to the organic COCOMO formula, the *estimated project effort*

Proj Serial	KDSI (est)	MM (est)	TDEV (est)	KDSI (act)	MM (actual)	TDEV(act)	Coefficient	Productivity	Comp Prod	Avg. Staff
CYCLE #1 (ESTIMATES)				**CYCLE #1 (ACTUALS - SIMULATED)**						
1	24	67.5	12.4	40	120.9	18.5		0.33		6.5
2	40	115.4	15.2	50	149.7	18.6		0.33		8
3	42	121.5	15.5	60	187.6	19.9		0.32		9.4
4	35	100.3	14.4	70	245.8	21.9		0.28		11.2
5	72	214	19.2	80	242.3	22.3	2.56	0.33	0.317	10.9
CYCLE #2 (ESTIMATES)				**CYCLE #2 (ACTUALS - SIMULATED)**						
2	30	91	13.9	50	160.3	19.2		0.31		8.3
1	36	110.2	14.9	40	115.7	16.6		0.35		7
3	48	149.1	16.7	60	184.6	19.5		0.33		9.5
5	40	123.1	15.6	80	305.1	22.3		0.26		13.7
4	49	152.4	16.9	70	227.4	20.6	2.73	0.31	0.302	11
CYCLE #3 (ESTIMATES)				**CYCLE #3 (ACTUALS - SIMULATED)**						
4	56	187	18.2	70	221.3	20.2		0.32		11
3	36	117.6	15.3	60	198.6	19.5		0.3		10.2
1	20	63.4	12.1	40	124.8	18.4		0.32		6.8
2	45	148.6	16.7	50	156	18.2		0.32		8.6
5	56	187	18.2	80	273.1	21.4	2.64	0.29	0.308	12.8
CYCLE #4 (ESTIMATES)				**CYCLE #4 (ACTUALS - SIMULATED)**						
4	42	133.7	16.1	70	242.2	20.7		0.29		11.7
1	28	87.3	13.7	40	119.1	17.3		0.34		6.9
5	64	208	19	80	257.4	21.6		0.31		11.9
2	25	77.5	13.1	50	165	19.6		0.3		8.4
3	54	174	17.6	60	181.5	19.3	2.62	0.33	0.311	9.4
CYCLE #5 (ESTIMATES)				**CYCLE #5 (ACTUALS - SIMULATED)**						
5	48	152.6	16.9	80	286.2	21.7		0.28		13.2
4	63	203.1	18.8	70	214	20.5		0.33		10.4
2	35	109.5	14.9	50	153.4	18.4		0.33		8.3
3	30	93.2	14	60	203.5	20.3		0.29		10
1	32	99.7	14.4	40	117.6	16.9	2.66	0.34	0.308	7
CYCLE #6 (ESTIMATES)				**CYCLE #6 (ACTUALS - SIMULATED)**						
1	24	74.[illegible]	12.9	40	121.3	17.8		0.33		6.8
2	40	12[illegible]	15.8	50	150.4	18		0.33		8.4
3	42	134.7	16.1	60	191	19.4		0.31		9.8
4	35	111.2	15	70	252.9	21.1		0.28		12
5	72	237.2	20	80	250.1	21.8	2.62	0.32	0.311	11.5

Table 12. Conventional Calibration Strategy

(MM(est)) and *estimated project schedule* (TDEV(est)) are determined. All required input parameters for the project simulation have now been calculated. They are, KDSI(act), DSIPTK (%) -- expressed as a numerical value based on the nominal simulator value of 60, Under (%) -- expressed as a decimal value, MM(est), and TDEV(est). Next, the SD simulator generates the actual effort (MM(act)) and actual schedule (TDEV(act)) values.

The second series of calculations presented in each project cycle in Appendix A, uses the simulated actual effort and schedule values of each of the five project serials to determine the COCOMO calibration coefficient (Coefficient) which will be applied to all projects in the subsequent project cycle. Coefficient calculation is based on a series of well-defined computations as described in Chapter II. In the case of project cycle one, the Coefficient of 2.56 reflects an upward adjustment from the organic COCOMO value of 2.4. If this "conventional" calibration strategy is effective, this higher value, when applied to project cycle two size estimations, should produce more accurate effort and schedule estimates. Figure 7 shows the movement of the COCOMO calibration coefficient over the six project cycles under the conventional calibration strategy.

In addition, actual project productivity (Productivity) and composite cycle productivity (Comp Prod) are also determined in Appendix A. Actual project productivity (Productivity) is defined as the actual size of the project (KDSI(act)) divided by the actual cost of the project (MM(actual)). Results of the experiment are displayed in Figure 8, and reflect individual project productivities between .27 and .43.

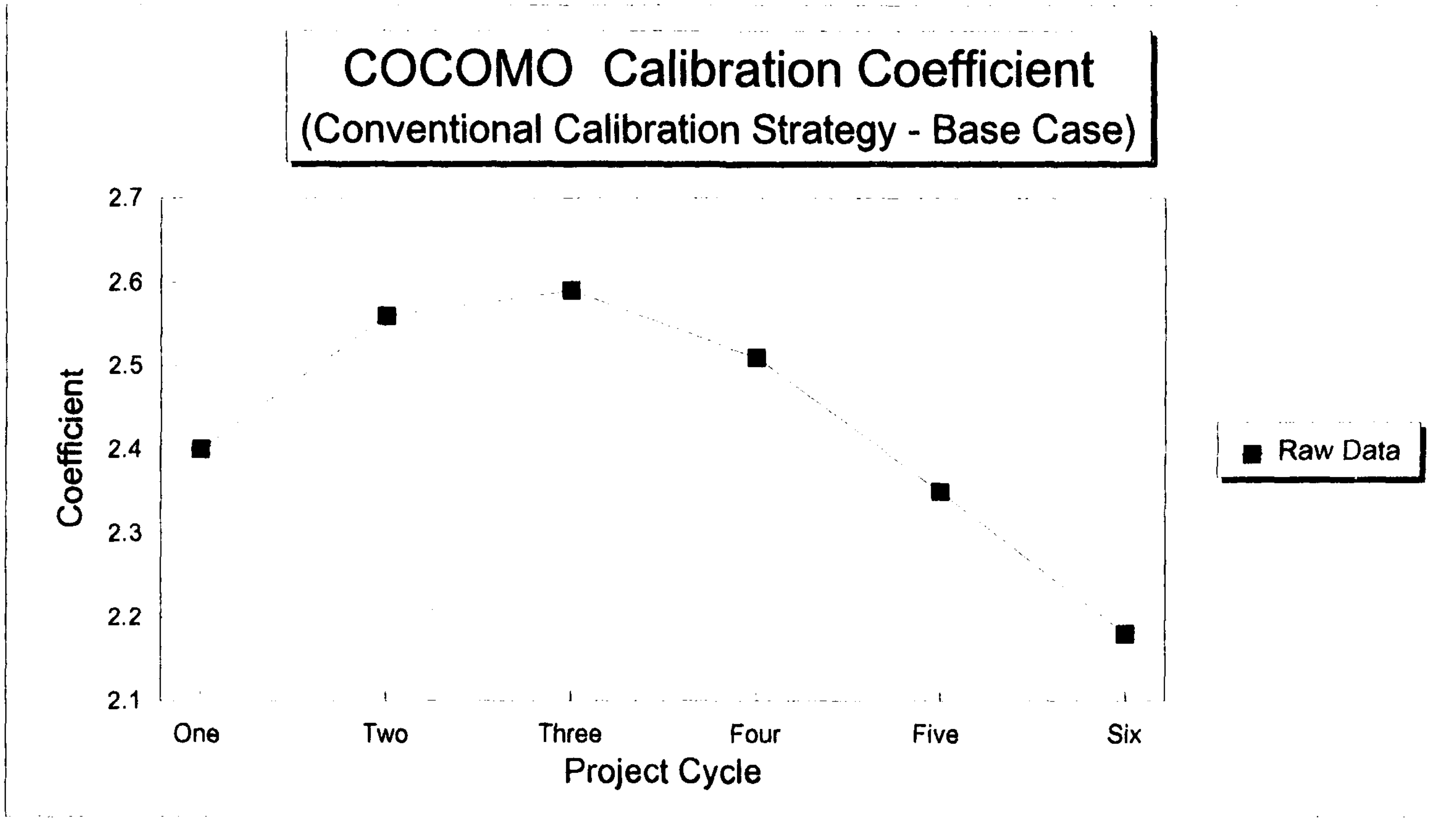

Figure 7. COCOMO Calibration Coefficient: Conventional Calibration Strategy - Base Case

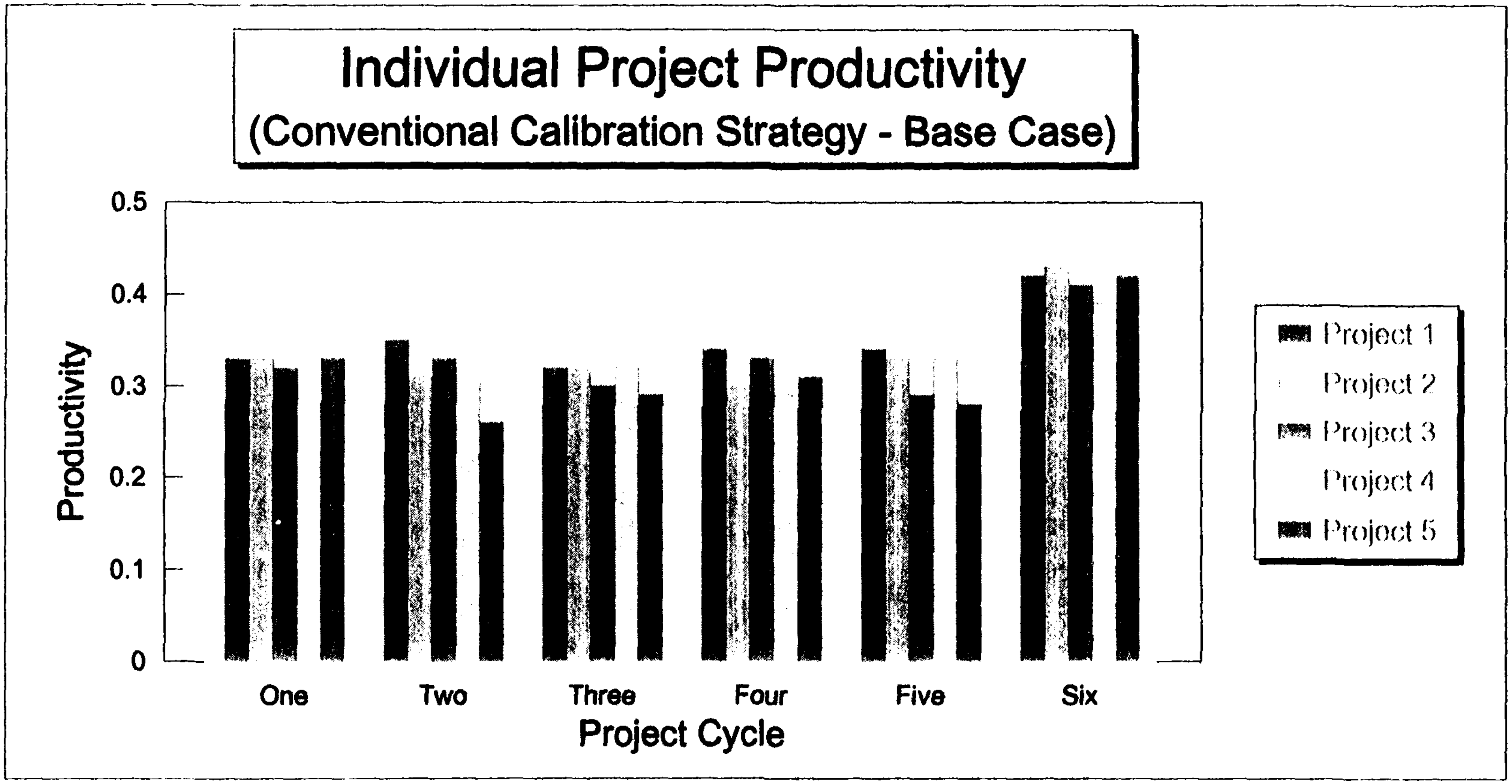

Figure 8. Productivity: Conventional Calibration Strategy - Base Case

Composite cycle productivity is defined as the total actual size of all projects in the cycle ($\sum$KDSI (act)), divided by the total actual effort of all projects ($\sum$MM (act)). In the conventional calibration scenario, overall composite productivity of the software development organization through the six project cycles improved from .317 to .411 (29.65 percent). Figure 9 captures this upward movement of composite productivity.

3. Alternative Calibration Strategy

The methodology employed in applying the alternative calibration strategy is identical to the conventional strategy described in the previous section, with one important exception. As described in Chapter II, upon determination of actual cost and schedule values using conventional COCOMO techniques, the projects are re-simulated with actual size and actual schedule inputs fixed. Cost estimates are gradually reduced from the actual simulated value until the optimum savings, or "normalized" cost value, is achieved. Appendix B provides all data on the normalization process for each of the five project serials over the six project cycles. Shaded cells in the MM(act) column represent the optimum or "normalized" value for that particular project. This value, referred to as MM(norm), is incorporated in the organizational data base and is used to calculate the new COCOMO calibration coefficient. Appendix C presents all calculations and data associated with the calibration of COCOMO using normalized data. Note its similarities with Appendix A. However, in the second series of calculations for each project cycle, the normalized effort (MM(norm)) is a new column entry. Its value was computed as part of the normalization process and transferred directly from the shaded cells in

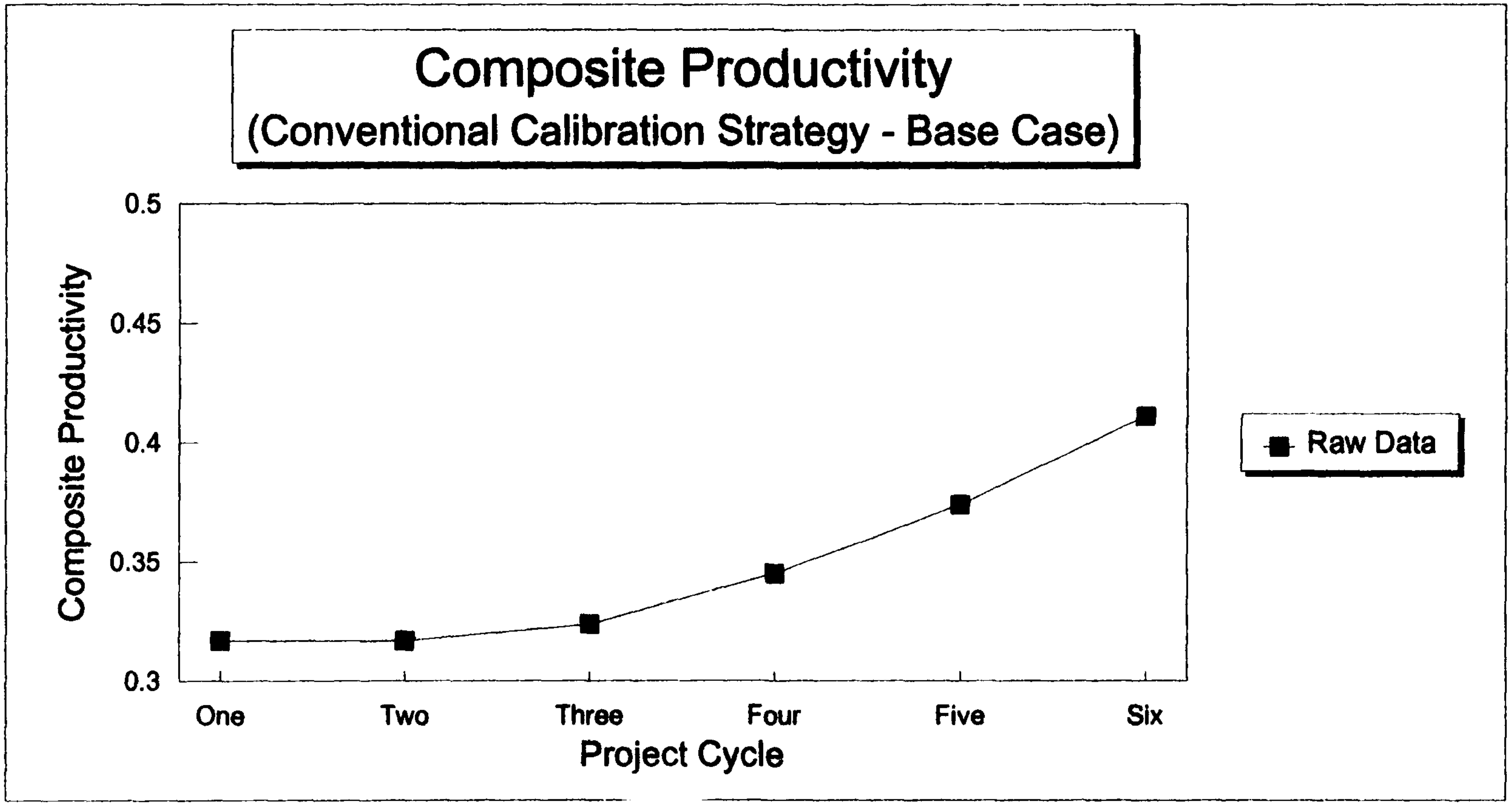

Figure 9. Composite Productivity: Conventional Calibration Strategy - Base Case

Appendix B. It is this value, MM(norm), which generates the new COCOMO coefficient, and not the actual effort cost value (MM(act)), as in the conventional calibration strategy.

It is important to note that normalization of the effort cost data has no *direct* impact on project productivity or composite cycle productivity, as actual effort costs continue to be used in computing these values. Normalization is primarily a process by which the inefficiencies which have plagued a problematic software development project can be eliminated. In so doing, it is possible for an organization to optimize the accuracy and representativeness of archived data for future estimation of similar projects.

A by-product of the normalization process, however, *is* improved productivity. In theory, normalization provides the organization with more optimal calibration coefficients which should lead to more optimal estimations. As inefficiencies are eliminated in project estimation, simulations produce projects with lower actual costs, which in turn, lead to improved productivity. These notions are borne out in the experimental findings summarized in Figure 10 and Table 13 -- a comparison of the previously-determined raw historical data with the normalized data recorded upon re-simulation of the identical project set. Improvement percentages for normalized data versus raw data are calculated in Table 13 for actual cost, productivity, and composite productivity values. Note that beginning with project cycle two (when the normalization process first produces a unique calibration coefficient), improvement is noted across all entries. While improvements

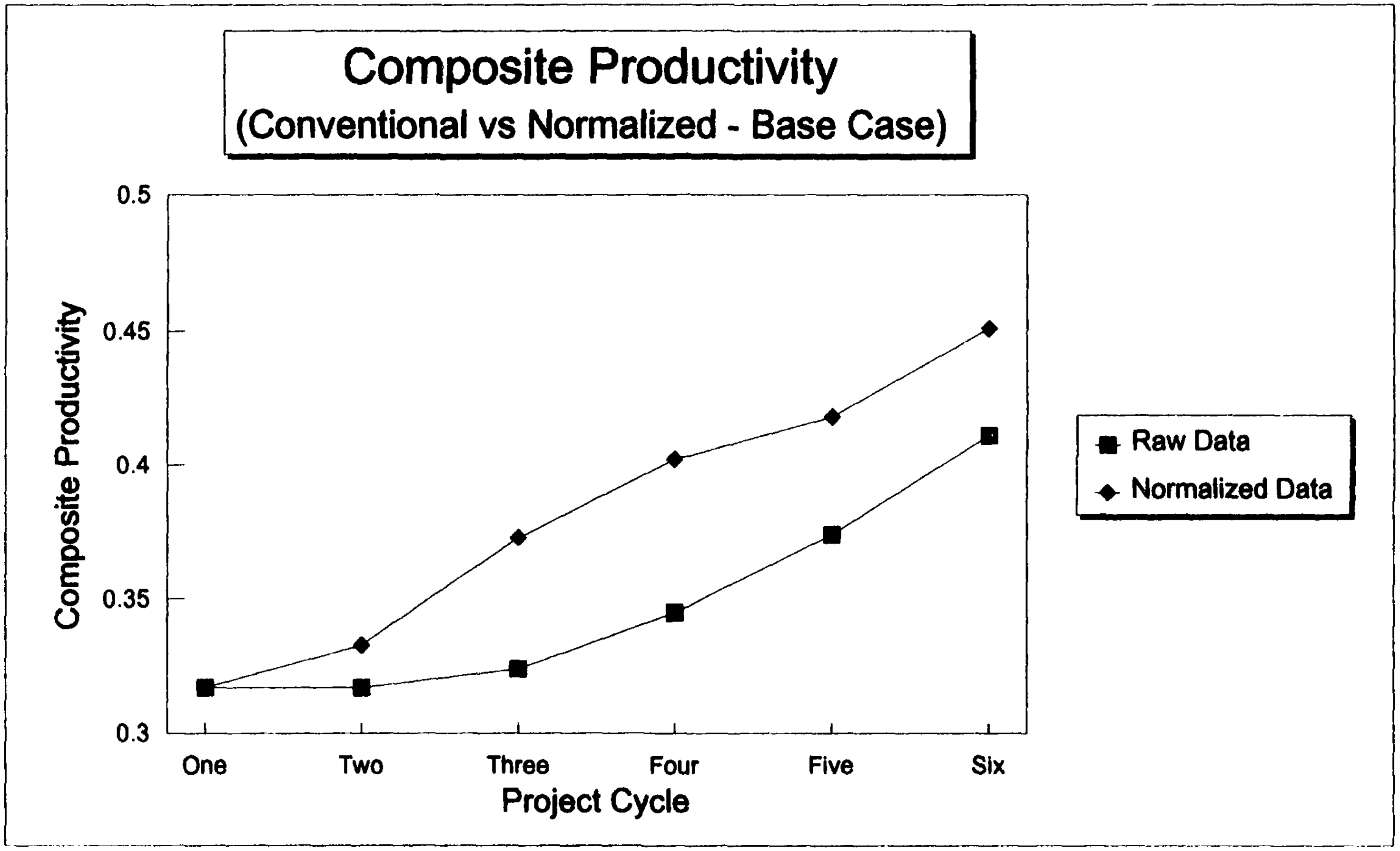

Figure 10. Composite Productivity - Base Case

Cycle & Project		Raw Data				Normalized Data				Percent Improvement		
Cycle #	Project #	DSIPTK (%	MM (act)	Productivity	Comp.Prod	DSIPTK (%	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod
1	1	100%	120.9	0.33		100%	120.9	0.33		0.00%	0.00%	
1	2	100%	149.7	0.33		100%	9.7	0.33		0.00%	0.00%	
1	3	100%	187.6	0.32		100%	187.6	0.32		0.00%	0.00%	
1	4	100%	245.8	0.28		100%	245.8	0.28		0.00%	0.00%	
1	5	100%	242.3	0.33	0.317	100%	242.3	0.33	0.317	0.00%	0.00%	0.00%
2	2	120%	147.3	0.34		120%	142.7	0.35		3.12%	2.94%	
2	1	120%	117.7	0.34		120%	107.6	0.37		8.58%	8.82%	
2	3	120%	178.6	0.34		120%	165.9	0.36		7.11%	5.88%	
2	5	120%	291.4	0.27		120%	277.9	0.29		4.63%	7.41%	
2	4	120%	209.9	0.33	0.317	120%	207.7	0.34	0.333	1.05%	3.03%	5.05%
3	4	140%	216.5	0.32		140%	182.1	0.38		15.89%	18.75%	
3	3	140%	189.2	0.32		140%	164.8	0.36		12.90%	12.50%	
3	1	140%	123.1	0.32		140%	104.6	0.38		15.03%	18.75%	
3	2	140%	147	0.34		140%	122.7	0.41		16.53%	20.59%	
3	5	140%	251.2	0.32	0.324	140%	229.9	0.35	0.373	8.48%	9.38%	15.12%
4	4	160%	212.1	0.33		160%	188	0.37		11.36%	12.12%	
4	1	160%	111.1	0.36		160%	92.3	0.43		16.92%	19.44%	
4	5	160%	233.8	0.34		160%	199.9	0.4		14.50%	17.65%	
4	2	160%	146.9	0.34		160%	128	0.39		12.87%	14.71%	
4	3	160%	165.7	0.36	0.346	160%	138.5	0.43	0.402	16.42%	19.44%	16.52%
5	5	180%	225.9	0.35		180%	215.1	0.37		4.78%	5.71%	
5	4	180%	180	0.39		180%	164.4	0.45		14.22%	15.38%	
5	2	180%	130.6	0.39		180%	111.6	0.45		14.55%	18.42%	
5	3	180%	165.3	0.36		180%	151.9	0.39		8.11%	8.33%	
5	1	180%	100.5	0.4	0.374	180%	85.1	0.47	0.418	15.32%	17.50%	11.76%
6	1	200%	95.3	0.42		200%	84.1	0.48		11.75%	14.29%	
6	2	200%	117.2	0.43		200%	103.2	0.48		11.95%	11.63%	
6	3	200%	145.8	0.41		200%	130.9	0.46		10.22%	12.20%	
6	4	200%	180.5	0.39		200%	176.6	0.4		2.16%	2.56%	
6	5	200%	191.7	0.42	0.411	200%	170	0.47	0.451	11.32%	11.90%	9.73%

Table 13. Comparison of Conventional and Normalized Calibration Strategies - Base Case

are noted in productivity values associated with both raw and normalized data, the more dramatic results achieved through data normalization is apparent.

Of particular significance is the improvement in composite cycle productivity evident within both the raw and normalized data sets themselves. Over the course of the six project cycles, composite productivity, as determined under the conventional calibration strategy improved by 29.65 percent (from .317 to .411). Even more impressively, under the normalization strategy, composite productivity values improved by 42.27 percent (from .317 to .451). Recalling that in this scenario, experimental assumptions include both learning and undersizing, it is logical to pursue investigation of alternative scenarios in an effort to isolate and examine the effects of these assumptions.

The proper use of normalized effort cost data can have a significant impact on future software development costs. Table 14 summarizes actual project effort (MM(act)) under both the conventional and normalized calibration strategies. In addition, the table includes information on *potential* savings which may be achieved by archiving normalized data in the organizational data base vice the actual cost data. These savings could result when, in the future, the organization is faced with estimation of a project of similar size and scope. By using normalized data as input, estimates would not be biased by the inefficiencies which plagued the previous project. The potential savings in our problem set are noteworthy, both in terms of real effort cost savings (2.2 to 34.4 man-months) and percentage of reduction in cost (1.05 to 16.92 percent). Figure 11 graphically represents

Cycle and Project Information			Actual Project Effort		Potential Savings Through Normalization	
			Conventional	Normalized		
Cycle #	Proj.Serial	KDSI (act)	MM (act)	MM(act)	MM	Percent
1	1	40	120.9	120.9	0	0.00%
1	2	50	149.7	149.7	0	0.00%
1	3	60	187.6	187.6	0	0.00%
1	4	70	245.8	245.8	0	0.00%
1	5	80	242.3	242.3	0	0.00%
2	2	50	147.3	142.7	4.6	3.12%
2	1	40	117.7	107.6	10.1	8.58%
2	3	60	178.6	165.9	12.7	7.11%
2	5	80	291.4	277.9	13.5	4.63%
2	4	70	209.9	207.7	2.2	1.05%
3	4	70	216.5	182.1	34.4	15.89%
3	3	60	189.2	164.8	24.4	12.90%
3	1	40	123.1	104.6	18.5	15.03%
3	2	50	147	122.7	24.3	16.53%
3	5	80	251.2	229.9	21.3	8.48%
4	4	70	212.1	188	24.1	11.36%
4	1	40	111.1	92.3	18.8	16.92%
4	5	80	233.8	199.9	33.9	14.50%
4	2	50	146.9	128	18.9	12.87%
4	3	60	165.7	138.5	27.2	16.42%
5	5	80	225.9	215.1	10.8	4.78%
5	4	70	180	154.4	25.6	14.22%
5	2	50	130.6	111.6	19	14.55%
5	3	60	165.3	151.9	13.4	8.11%
5	1	40	100.5	85.1	15.4	15.32%
6	1	40	95.3	84.1	11.2	11.75%
6	2	50	117.2	103.2	14	11.95%
6	3	60	145.8	130.9	14.9	10.22%
6	4	70	180.5	176.6	3.9	2.16%
6	5	80	191.7	170	21.7	11.32%

Table 14. Potential Savings Through Normalization

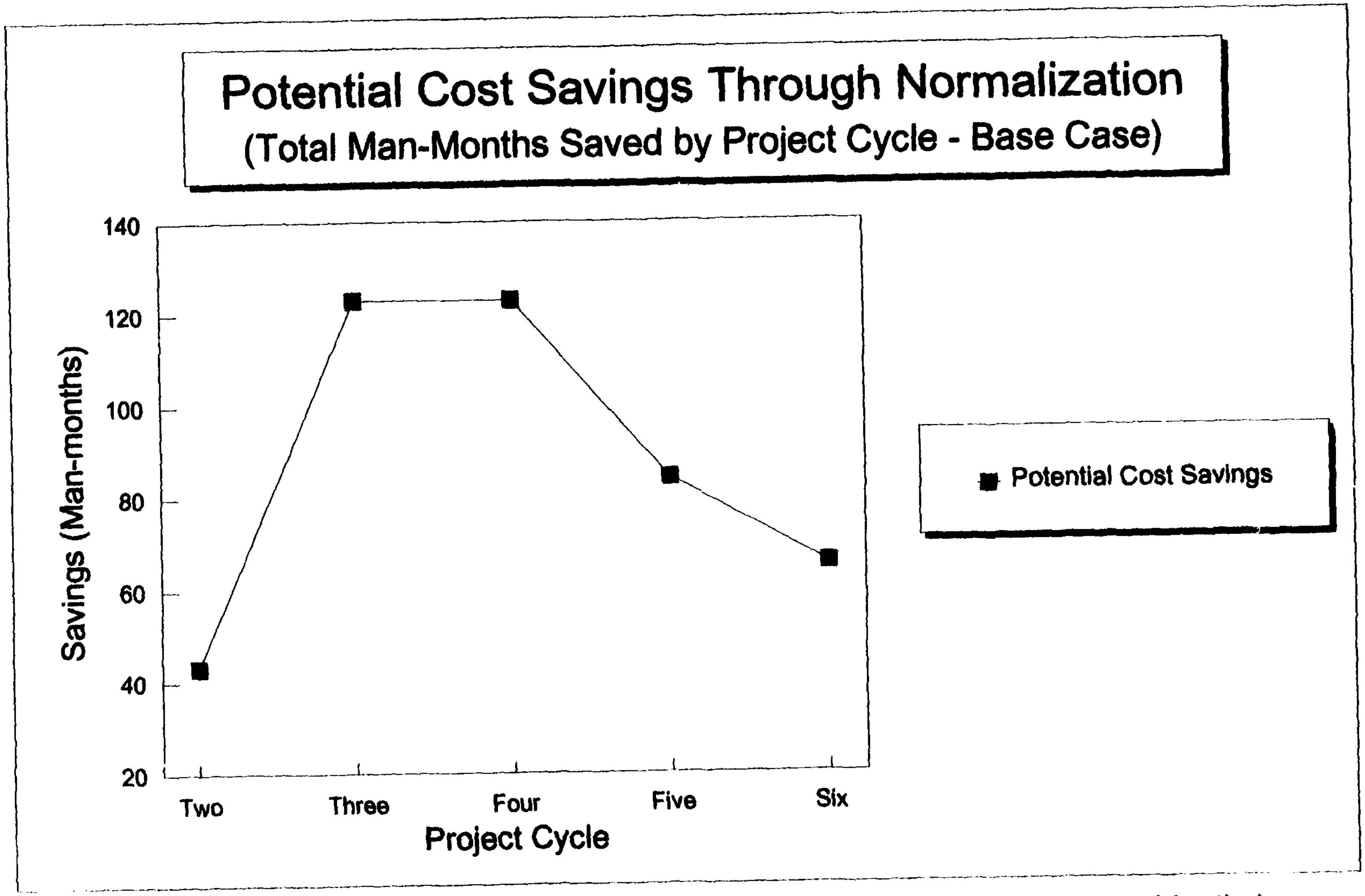

Figure 11. Potential Cost Savings Achievable Through Normalization (Man-Months)

the potential cost savings achievable through normalization of all projects, beginning with project cycle two.

These savings are possible since normalization removes the inefficiencies which lead to smaller COCOMO coefficients, which in turn, lead to "tighter" (i.e., smaller) cost estimates. On the other hand, the conventional calibration strategy produces higher calibration coefficients which subsequently lead to larger size estimates (Figure 12). As discussed in Chapter II, these higher-than-ideal estimates significantly influence the project's final results. Work expands to fill the available slack time, and the self-fulfilling prophecy of Parkinson's Law is realized once again (Boehm, 1981, p. 592).

Estimated project productivity was calculated as a measure by which the effects of project size underestimation could be observed on project behavior and outcome. Its calculation differs from that of actual productivity in that the actual size of the project (KDSI(act)) is divided by the COCOMO-generated estimate of project cost based on *no size underestimation* (MM(est)). With post-facto knowledge of a project's actual size, an estimated project effort value can be generated for the denominator value (MM(est)). Figure 13 plots estimated project productivity versus project size for project cycle one and both the conventional and normalized estimated productivity values for project cycle six. It is clear from the plot that estimated productivity decreases as project size increases in all three instances.

As defined, the estimated productivity value should "shadow" the actual productivity value as it relates to the COCOMO-calibrated project effort estimate. When compared

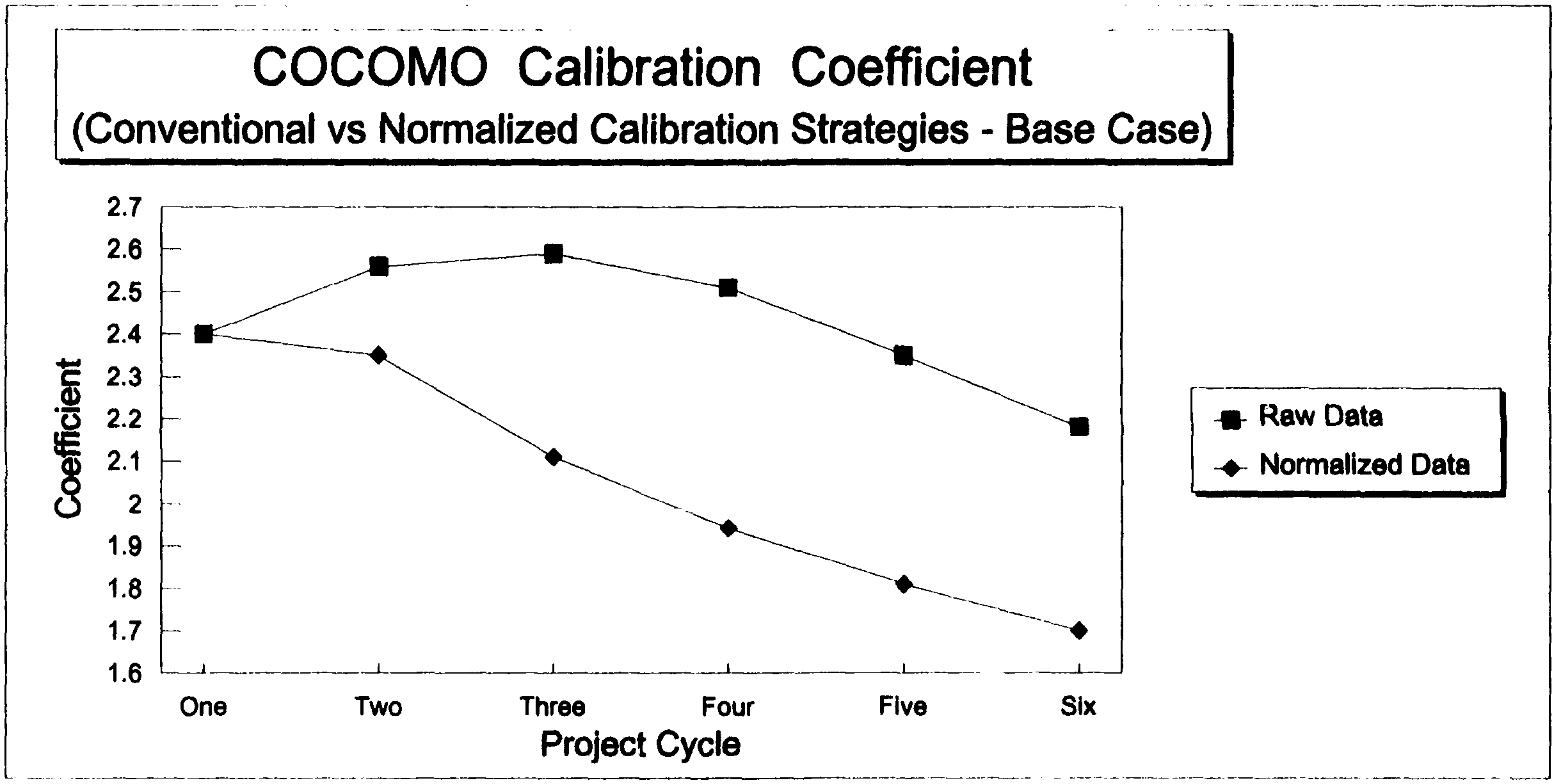

Figure 12. COCOMO Calibration Coefficient: Conventional vs Normalized - Base Case

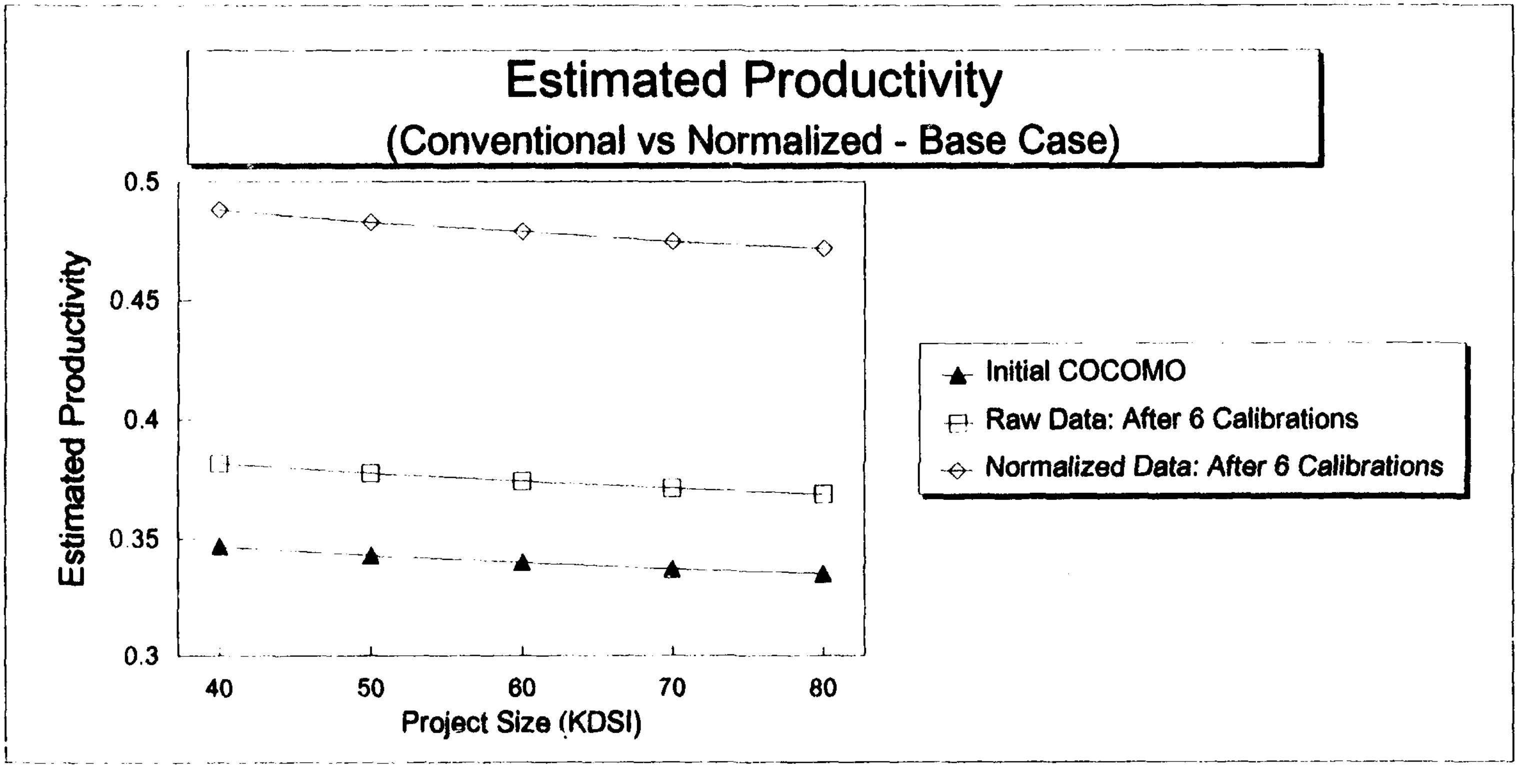

Figure 13. Estimated Productivity - Base Case

against actual project productivity, estimated project productivity provides an indication of the relative accuracy and validity of the software estimation tool and its calibration coefficient. Figures 14, 15, and 16 compare actual versus estimated project productivity as a function of project size for project cycles one and both the raw and normalized instances of project cycle six, respectively. In Figure 14, the trend toward convergence of the actual and estimated productivity values appears loosely related to initial project undersizing. For example, the project with the smallest size underestimation (80 KDSI with 10% underestimation) has an actual productivity figure closest to its estimated productivity value. Likewise, the actual productivity of the project with the largest undersizing (70 KDSI with 50% underestimation) is furthest away from its estimated counterpart.

From Figure 13, it is evident that the conventional COCOMO calibration method has lead to estimated productivity values in project cycle six approximately 10 percent more than similar projects in cycle one. The normalization method yields values nearly 41 percent higher than cycle one. Nevertheless, from Figure 15, conventional cycle six actual productivity values exceeded their estimates by between 5.1 and 14 percent. With the exception of the largely undersized project (70 KDSI, 50-percent undersizing), the normalization strategy, shown in Figure 16, provides the best "fit", with estimated productivities exceeding actual productivities by an average of less than 1.5 percent.

This fact is also confirmed by using the completed project results for ex-post-facto evaluation of the accuracy of the COCOMO estimation model. The percentage of

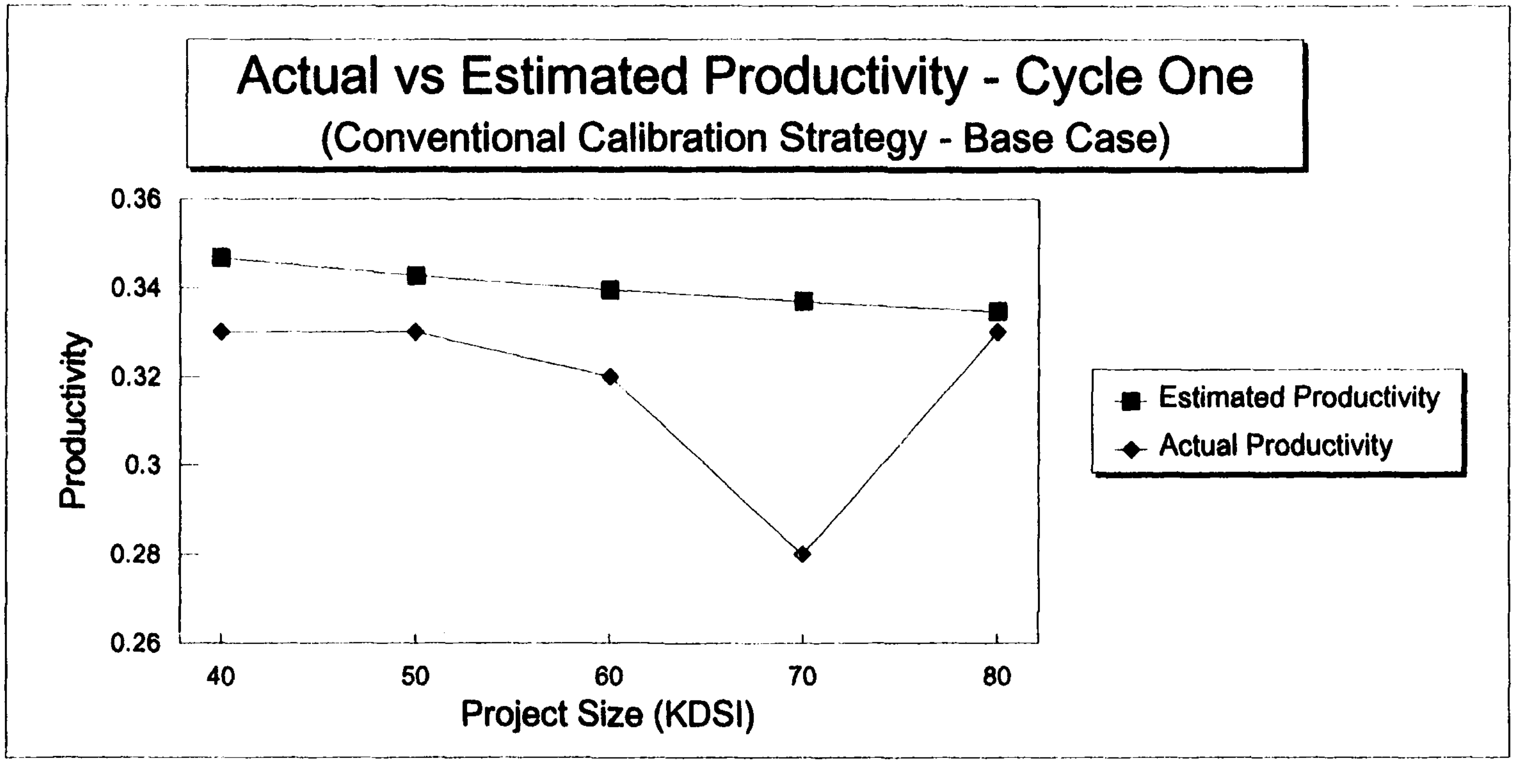

Figure 14. Actual vs Estimated Productivity: Cycle One - Conventional Strategy - Base Case

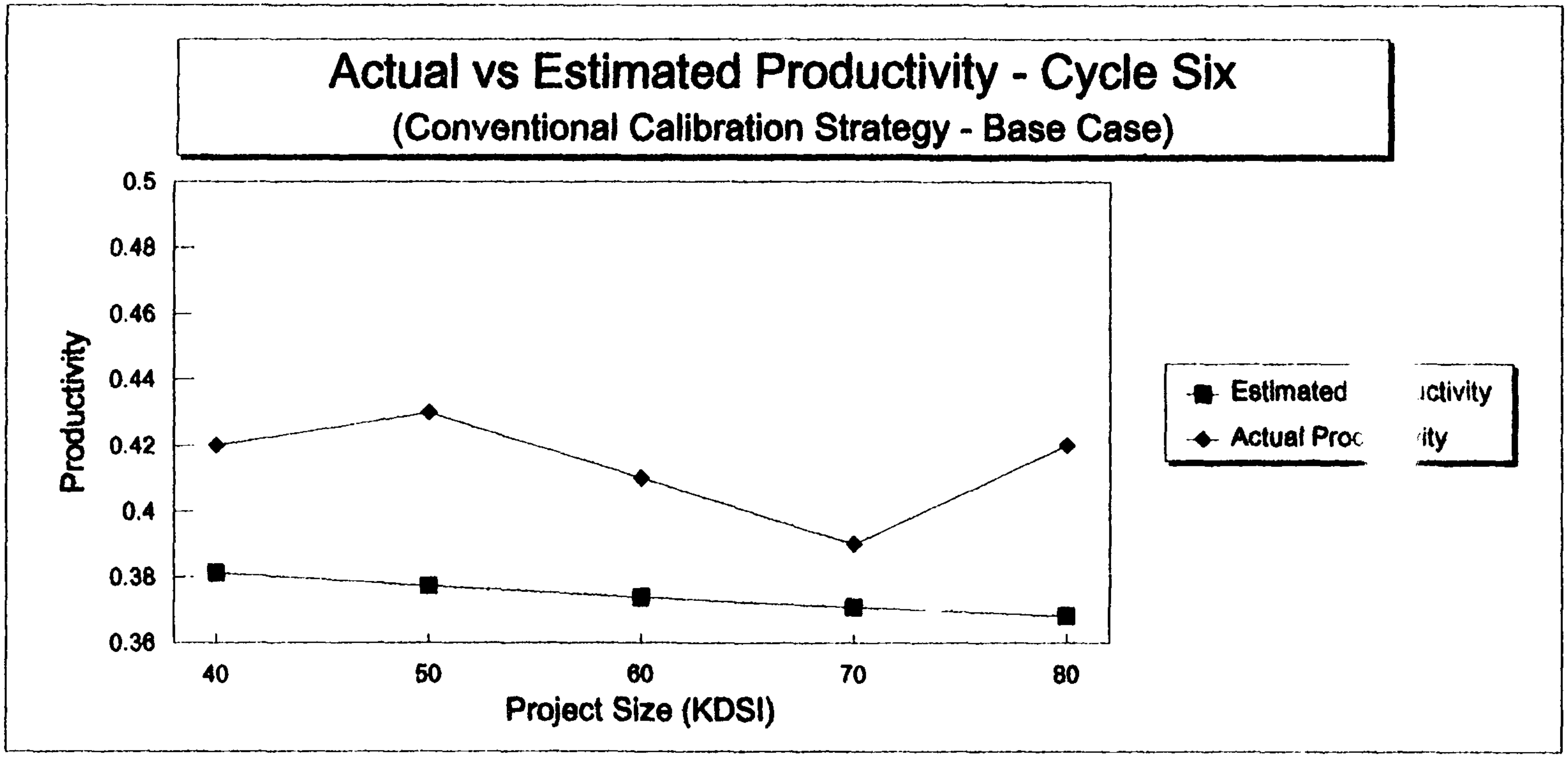

Figure 15. Actual vs Estimated Productivity: Cycle Six - Conventional Strategy - Base Case

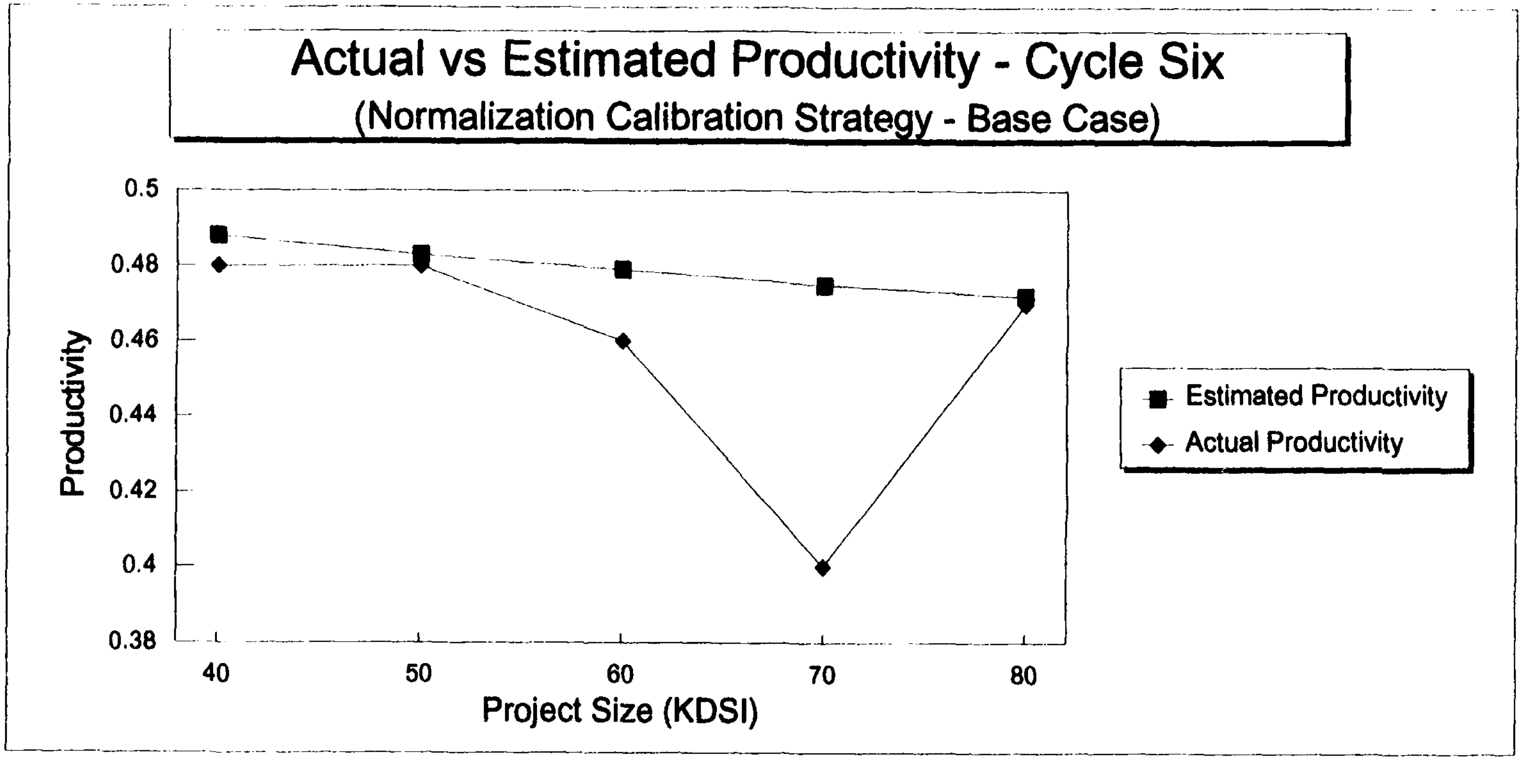

Figure 16. Actual vs Estimated Productivity: Cycle Six - Normalization Strategy - Base Case

relative error in the accuracy of project cost estimation can be caluclated using the following equation:

$$\text{Percent Relative Error} = \frac{100*|MM(act)-MM(est)|}{MM(act)} \tag{4.1}$$

Equation 4.1 is used to determine the accuracy of the base case estimates generated under both the conventional and normalized calibration strategies in cycles two through six of the exercise scenario. Figure 17 is a plot of the average error for all projects by project cycle, and the results suggest that the accuracy of COCOMO project cost estimation in this scenario favors the normalized calibration model over the conventional model.

C. EFFECTS OF NO UNDERSIZING ON BASE CASE RESULTS

Having concluded an examination of conventional versus normalized calibration strategies in a scenario that included both learning and undersizing (base case), the project set was re-simulated under similar conditions, but assuming no undersizing. The methodology was identical to the base case, with the exception that the SD simulator input UNDEST was set at "0" in each project simulation to reflect "perfect" size estimation. Appendices D, E, and F document the results of these re-simulations, again modeling both the conventional and normalized calibration strategies. The results are summarized in Table 15.

A comparison with the base case results (Table 13) reveals some interesting findings. With no undersizing, individual productivity improved in all projects and across all project cycles with respect to their undersized counterparts. In 18 of the 30 project serials, however, the *percentage* of improvement in productivity realized through the

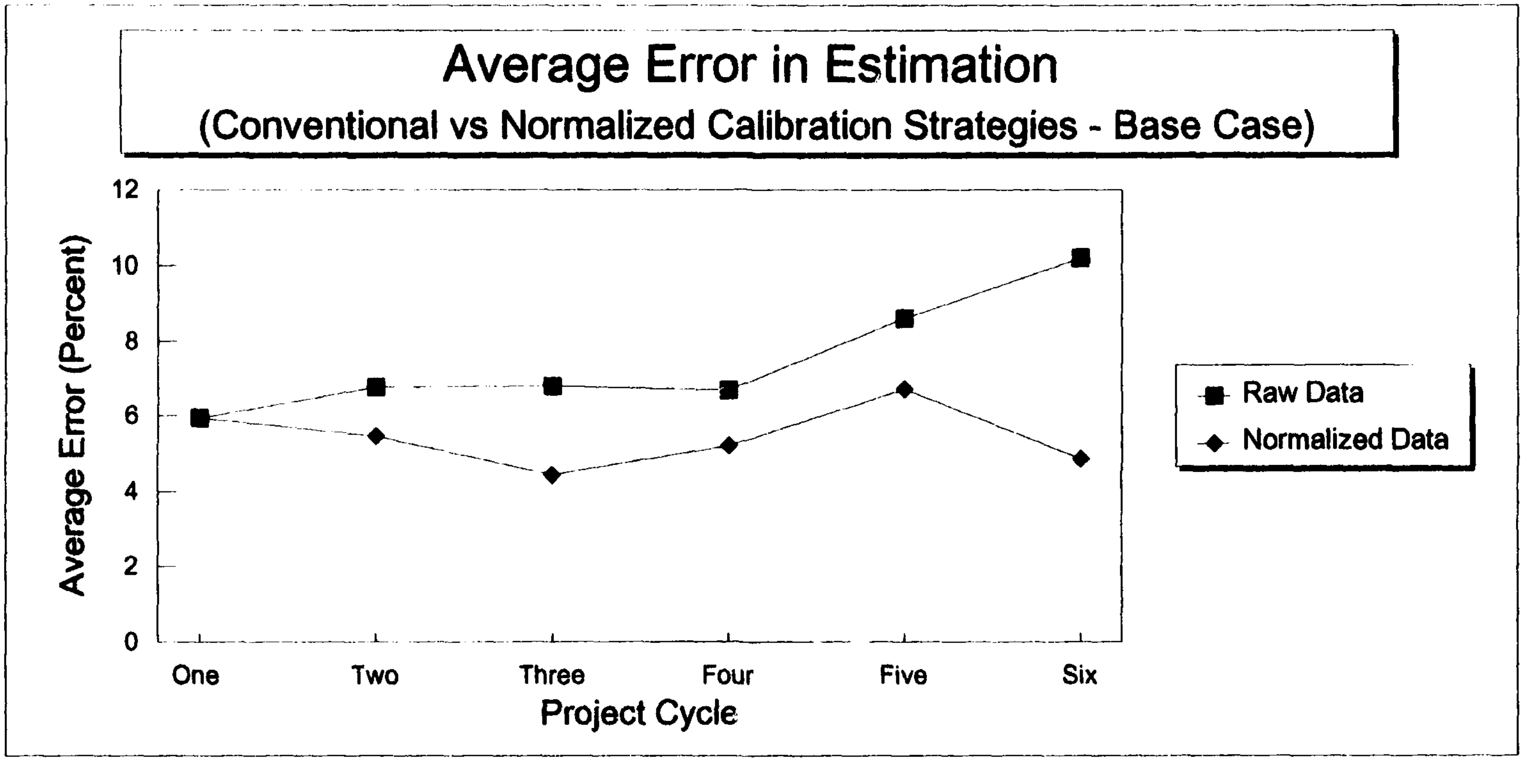

Figure 17. Average Error in Accuracy of Estimation of Project Cost: Conventional vs Normalized Calibration Strategies - Base Case

Cycle & Project		Raw Data				Normalized Data				Percent Improvement		
Cycle #	Project #	DSIPTK (%)	MM (act)	Productivity	Comp.Prod	DSIPTK (%)	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod
1	1	100%	115.4	0.35		100%	115.4	0.35		0.00%	0.00%	
1	2	100%	145.9	0.34		100%	145.9	0.34		0.00%	0.00%	
1	3	100%	178.3	0.34		100%	178.3	0.34		0.00%	0.00%	
1	4	100%	212	0.33		100%	212	0.33		0.00%	0.00%	
1	5	100%	246.7	0.32	0.334	100%	246.7	0.32	0.334	0.00%	0.00%	0.00%
2	2	120%	147.3	0.34		120%	142.4	0.35		3.33%	2.94%	
2	1	120%	116.6	0.34		120%	112.6	0.36		3.43%	5.88%	
2	3	120%	178.2	0.34		120%	172.6	0.35		3.14%	2.94%	
2	5	120%	241.2	0.33		120%	233.7	0.34		3.11%	3.03%	
2	4	120%	209.7	0.33	0.336	120%	203.1	0.34	0.347	3.15%	3.03%	3.27%
3	4	140%	206.1	0.34		140%	182.1	0.38		11.64%	11.76%	
3	3	140%	174.4	0.34		140%	154.7	0.39		11.30%	14.71%	
3	1	140%	112.7	0.35		140%	101.4	0.39		10.03%	11.43%	
3	2	140%	143.2	0.35		140%	127.9	0.39		10.68%	11.43%	
3	5	140%	237.4	0.34	0.343	140%	209.4	0.38	0.387	11.79%	11.76%	12.83%
4	4	160%	191.2	0.37		160%	167.5	0.42		12.40%	13.51%	
4	1	160%	104.2	0.38		160%	93.1	0.43		10.65%	13.16%	
4	5	160%	222.6	0.36		160%	192.7	0.42		13.43%	16.67%	
4	2	160%	132.4	0.38		160%	117.7	0.42		11.10%	10.53%	
4	3	160%	161.4	0.37	0.37	160%	142.3	0.42	0.421	11.83%	13.51%	13.78%
5	5	180%	202.5	0.4		180%	179.6	0.45		11.31%	12.50%	
5	4	180%	174.8	0.4		180%	156.1	0.45		10.70%	12.50%	
5	2	180%	121.5	0.41		180%	109.6	0.46		9.79%	12.20%	
5	3	180%	148	0.41		180%	133	0.45		10.14%	9.76%	
5	1	180%	95.6	0.42	0.404	180%	86.7	0.46	0.451	9.31%	9.52%	11.63%
6	1	200%	[illegible]	0.46		200%	81.4	0.49		7.18%	6.52%	
6	2	200%	[illegible]	0.45		200%	103	0.49		7.54%	8.89%	
6	3	200%	135.3	0.44		200%	124.7	0.48		7.83%	9.09%	
6	4	200%	159.7	0.44		200%	146.8	0.48		8.08%	9.09%	
6	5	200%	184.6	0.43	0.442	200%	168.5	0.47	0.48	8.72%	9.30%	8.60%

Table 15. Comparison of Conventional and Normalized Calibration Strategies: Case With Learning and No Undersizing

normalization process, was *less* in this scenario (no undersizing) than in the base case (with undersizing). This is reflected in Figure 18, where a plot of the average improvement in productivities as a result of normalization shows minimal variance between the two scenarios.

Composite cycle productivities within the domain of the "no undersizing" scenario, again showed a significant improvement over the span of the six project cycles, with the conventional strategy yielding an improvement of 32.3 percent, and the normalization strategy 43.7 percent. These productivity improvements (without undersizing), however, are only marginally better than those realized in the base case (with undersizing). Figure 19 presents a graphical summary of composite cycle productivity, comparing raw and normalized results in both the undersizing and no-undersizing scenario. It is evident that by the third project cycle, composite productivity under the normalized calibration strategy surpasses the productivity values achieved under the conventional calibration strategy, regardless of whether or not the project's size was underestimated. This finding suggests that normalization may be an effective tool that can help offset the negative effects of project estimation undersizing. Nevertheless, further research is required to support this claim.

Estimated productivity comparisons under this scenario reveal some interesting results. With no undersizing, actual and estimated individual project productivities are nearly identical in cycle one (Figure 20). These values are the same in the conventional and normalized cases, since the initial effect of the normalization process is not evident

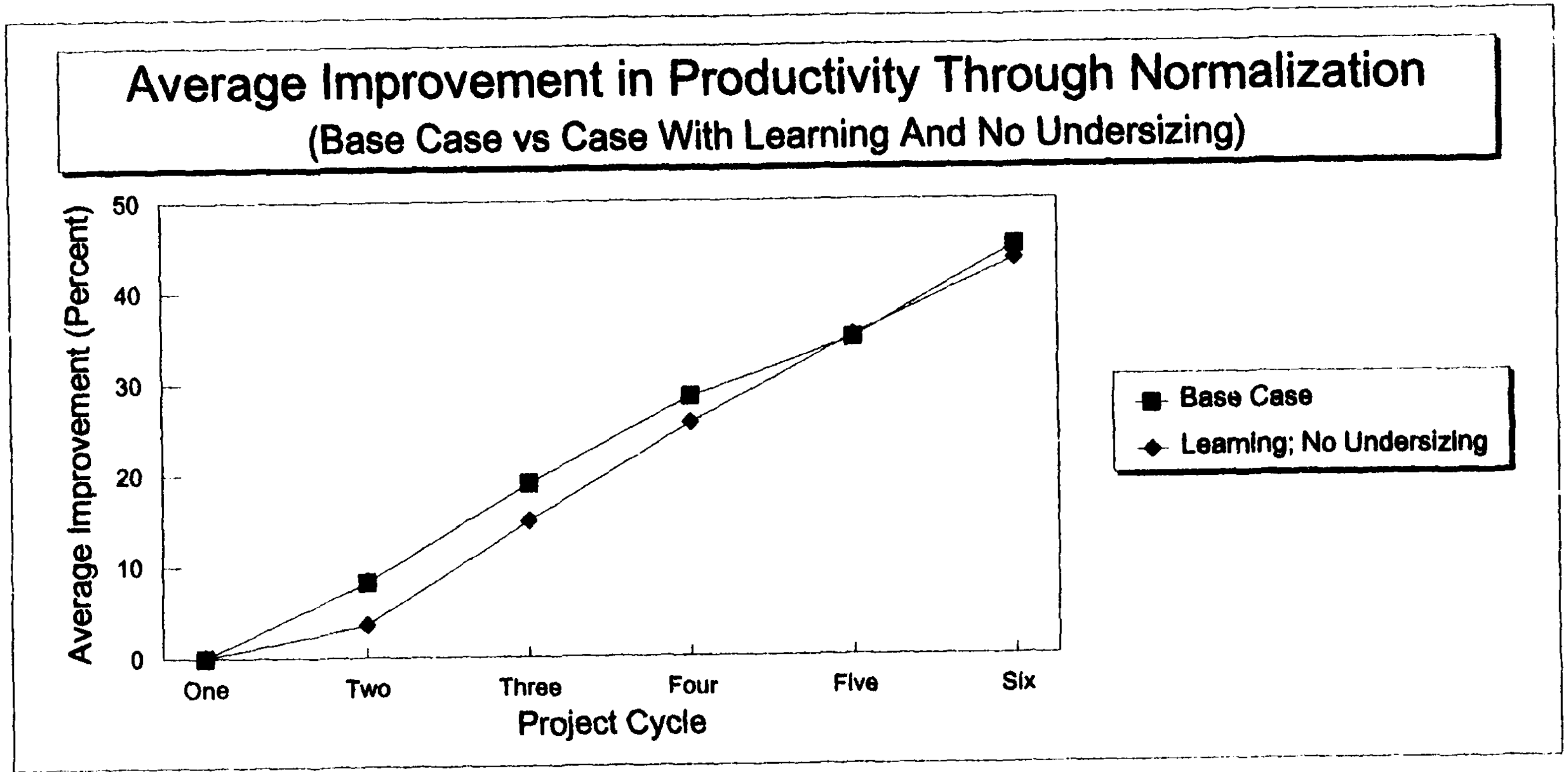

Figure 18. Average Improvement in Productivity: Base Case vs Case With Learning and No Undersizing.

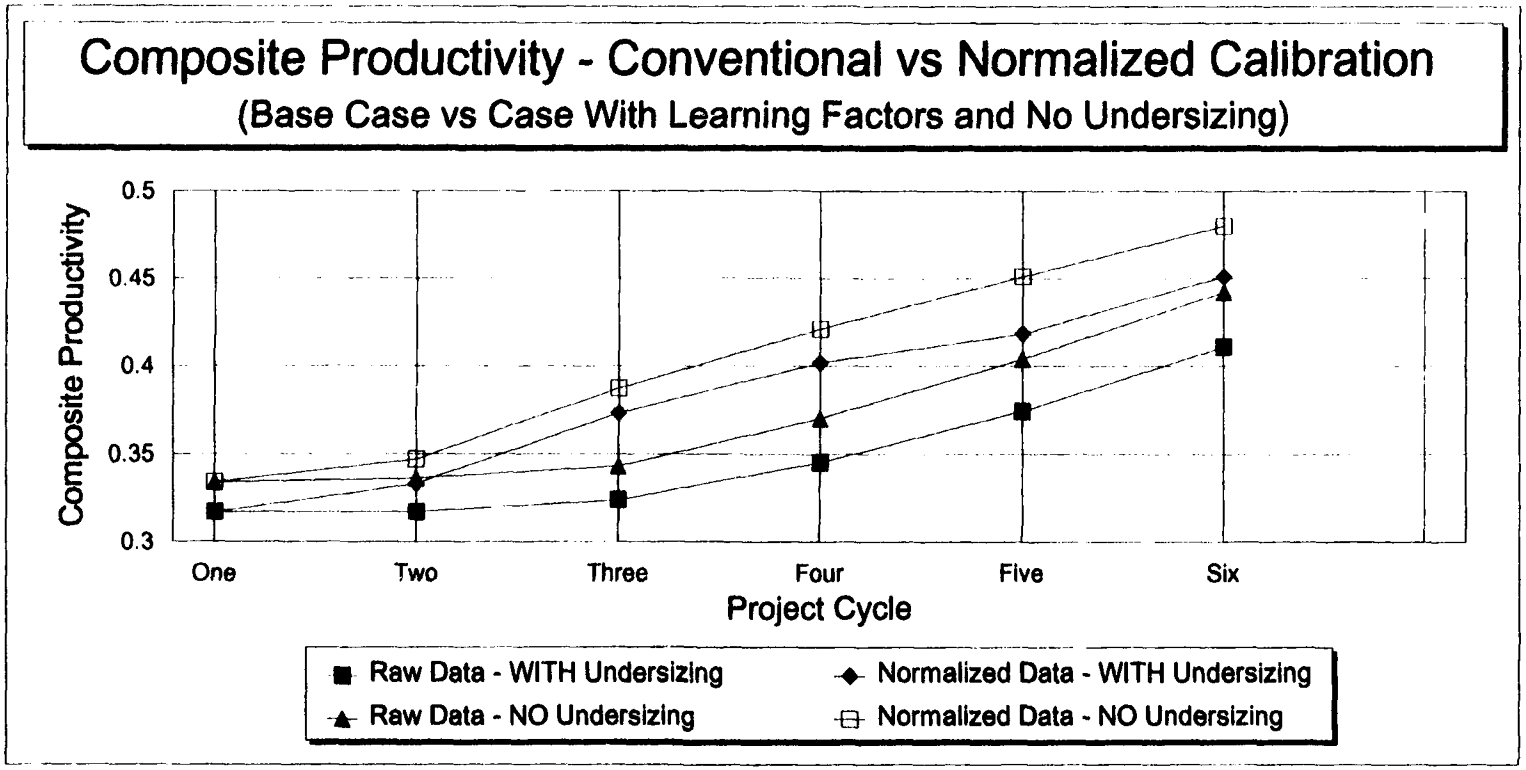

Figure 19. Composite Productivity: Conventional vs Normalized - Base Case vs Case With Learning and No Undersizing

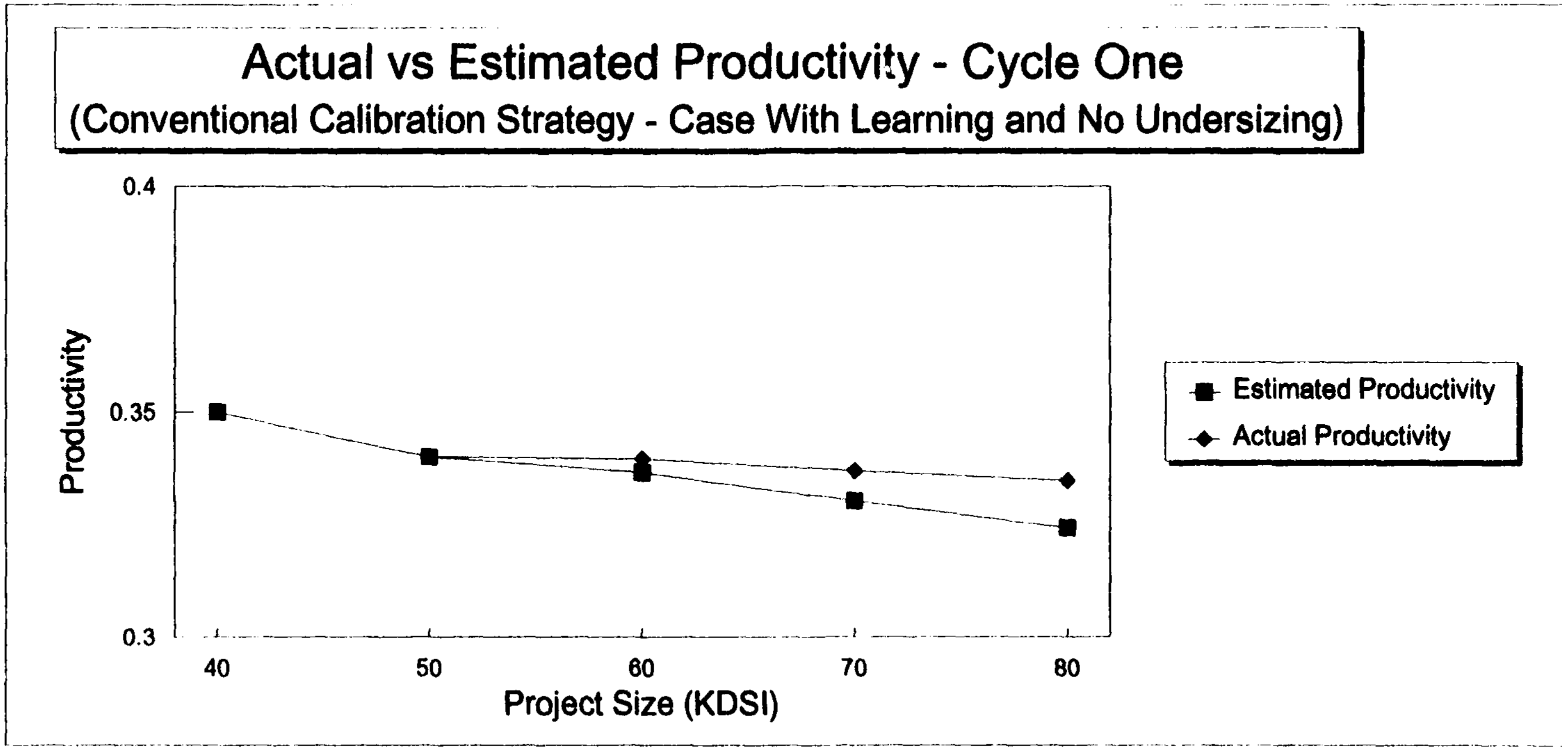

Figure 20. Actual vs Estimated Productivity: Cycle One - Conventional Strategy - Case With Learning and No Undersizing

until project cycle two. However, using the conventional strategy (raw data), estimates of productivity begin to drift, and by cycle six lag actual productivities by a range of 6.8 percent to 10.86 percent (Figure 21). Conversely, normalized data continues to produce precise estimates within one percent of actual productivity values in cycle six (Figure 22). This would indicate a more responsive calibration of the COCOMO constant by the normalization process in this scenario.

The relative error in the accuracy of COCOMO's project cost estimation under conventional and normalized calibration strategies is quite dramatic in this scenario of no undersizing, as can be clearly seen in Figure 23. With "perfect" size input, normalization of the data results in consistent COCOMO cost estimates across all project cycles, with a relative error rate of less than one-half percent. Conversely, while conventionally-calibrated COCOMO produces "tight" cost estimates in project cycles one and two, the error rate balloons to nearly ten percent by cycle six.

D. EFFECTS OF NO LEARNING ON BASE CASE RESULTS

In this experiment, the project set was re-simulated in a scenario which included undersizing, but assumed no learning between project cycles. The methodology differed from the base case only in the fact that the SD simulator parameter DSIPTK remained fixed at the default value of "60" for all project simulations. This effectively eliminated the learning assumption, by modeling the experiment with a "flat" delivered-source-instruction-per-task rate from cycle to cycle. Appendices G, H, and I document the results of the experiment.

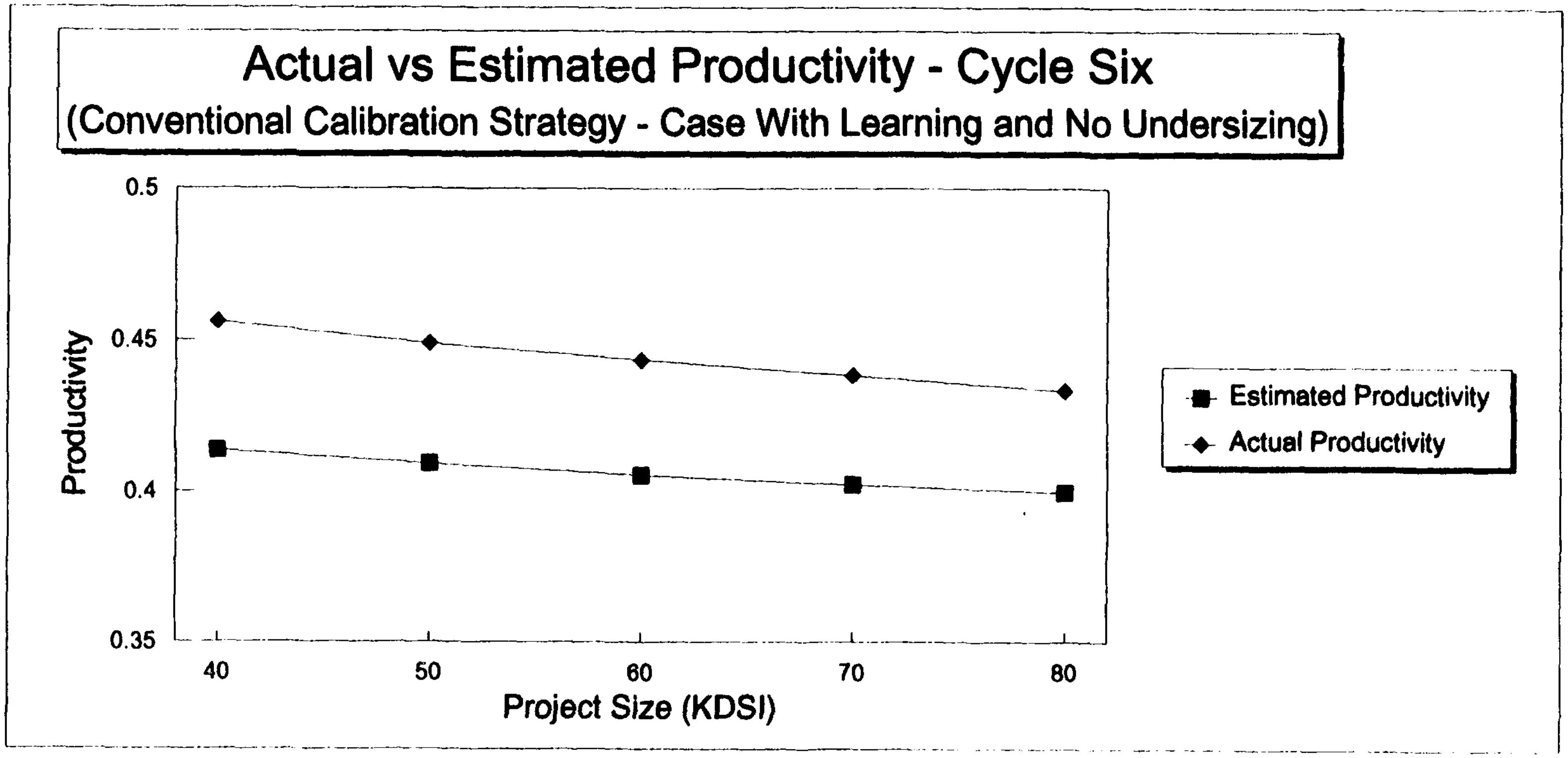

Figure 21. Actual vs Estimated Productivity: Cycle Six - Conventional Strategy - Case With Learning and No Undersizing

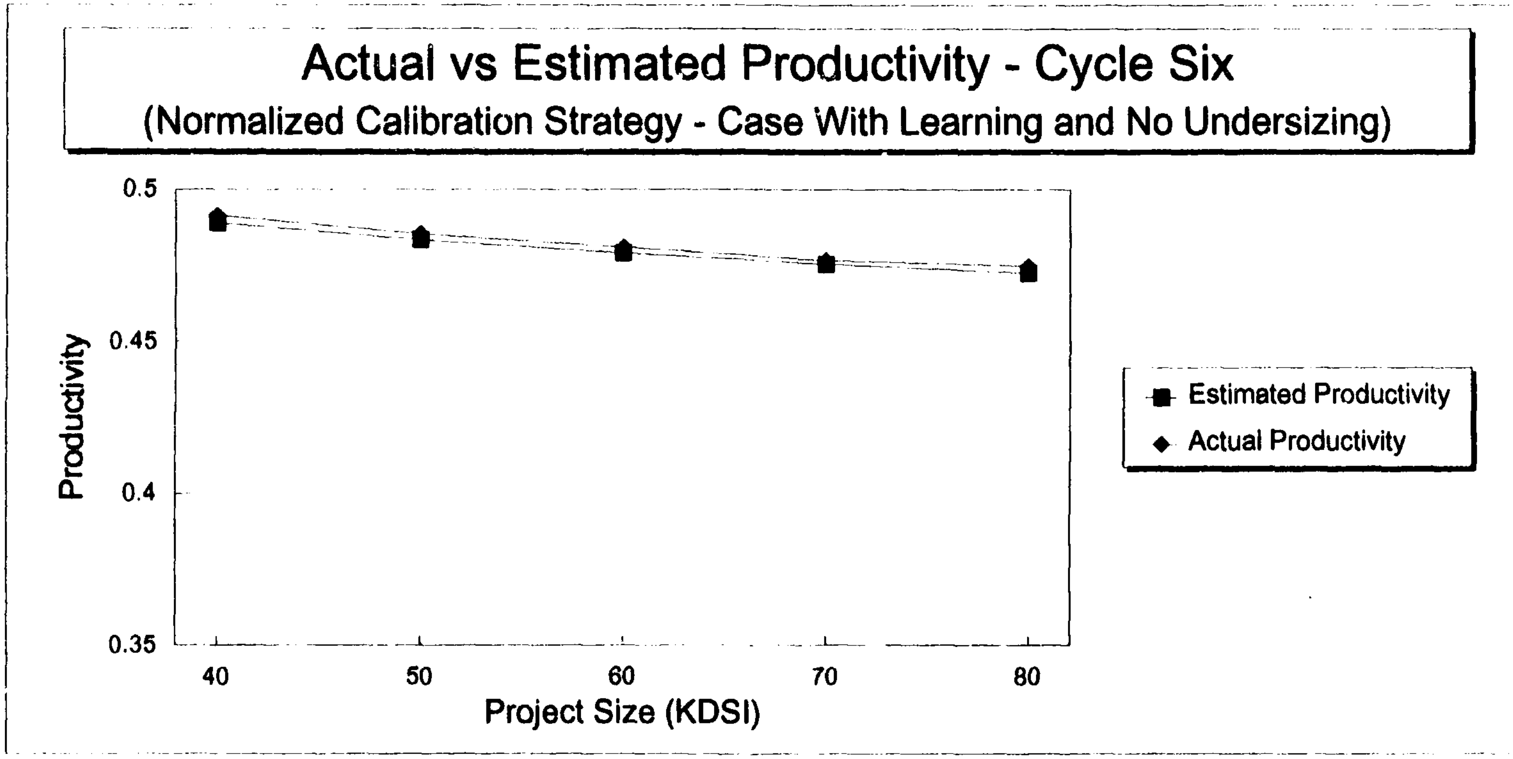

Figure 22. Actual vs Estimated Productivity: Cycle Six - Normalized Strategy - Case With Learning and No Undersizing

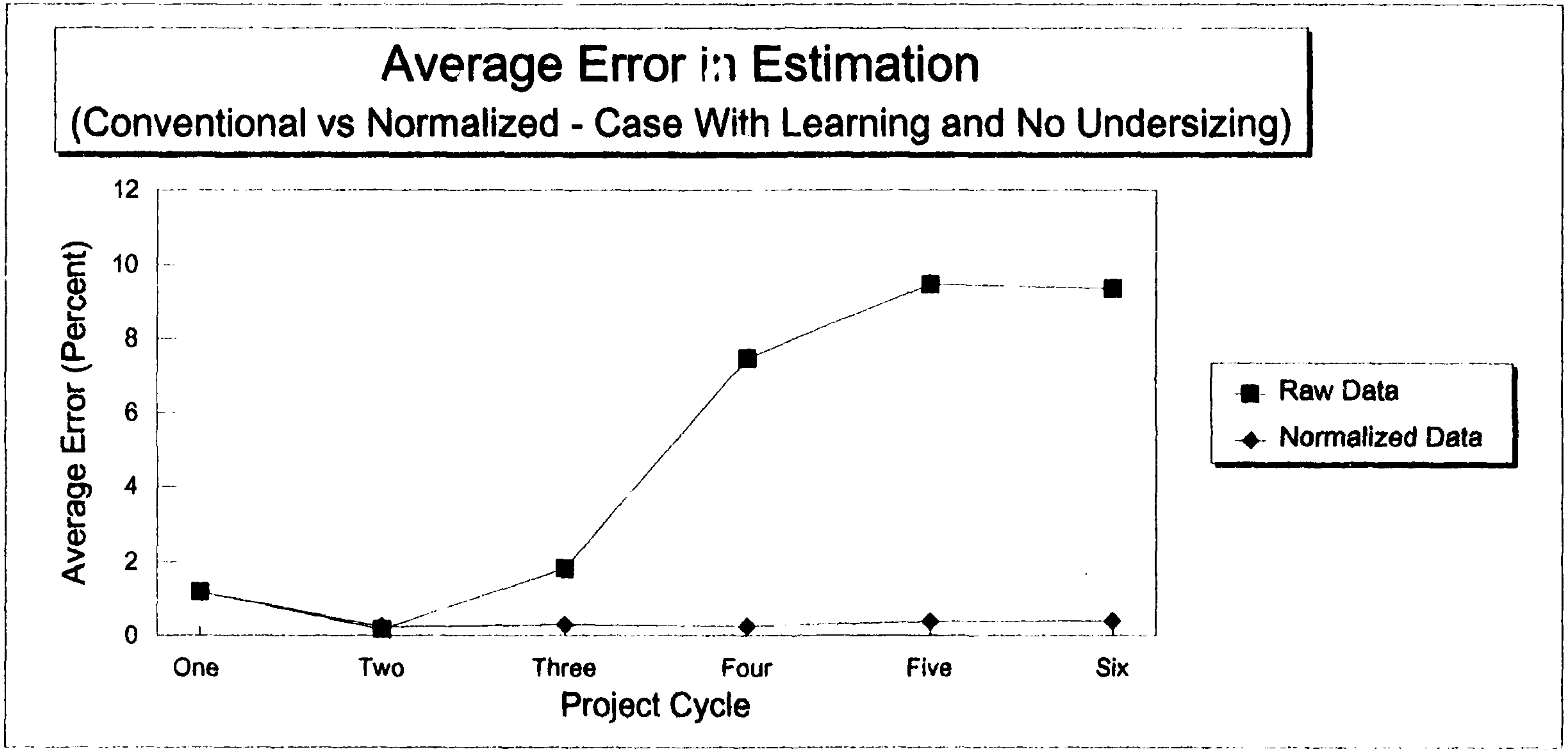

Figure 23. Average Error in Accuracy of Estimation of Project Cost: Case With Learning and No Undersizing

Results of the experiment are summarized in Table 16, and show that while individual project productivity using the conventional calibration strategy varied between .26 and .35, composite productivity through the six project cycles *decreased* marginally from .317 to .311 (1.89 percent). In this scenario (undersizing but no learning), the normalization strategy yielded minimal improvement, at best, over the conventional strategy in terms of real effort (-2.92 percent to 6.54 percent), individual project productivity (-3.85 percent to 6.25 percent) and composite productivity (.33 percent to 3.57 percent). In addition, with normalization, composite productivity over the six project cycles improved only trivially from .317 to .318 (.315 percent). These composite productivity values are graphically represented in Figure 24, and provide an important observation. The findings suggest that, in an environment devoid of learning, both the conventional *and* normalization calibration strategies are largely ineffective in improving productivity.

Similarly, both estimated productivity and relative accuracy values are inconclusive in this scenario. In the case of the conventional strategy, raw data values produce underestimates of productivity averaging 4.5 percent, while the normalization strategy yields overestimates averaging 8.9 percent. The accuracy of project cost estimation favors the conventional COCOMO calibration strategy in three of the five project serials, besting the normalized model's average relative error rate, 6.08 percent to 7.62 percent.

Cycle & Project		Raw Data			Normalized Data			Percent Improvement		
Cycle #	Project #	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod
1	1	120.9	0.33		120.9	0.33		0.00%	0.00%	
1	2	149.7	0.33		149.7	0.33		0.00%	0.00%	
1	3	187.6	0.32		187.6	0.32		0.00%	0.00%	
1	4	245.8	0.28		245.8	0.28		0.00%	0.00%	
1	5	242.3	0.33	0.317	242.3	0.33	0.317	0.00%	0.00%	0.00%
2	2	160.3	0.31		155.3	0.32		3.12%	3.23%	
2	1	115.7	0.35		115.1	0.35		0.52%	0.00%	
2	3	184.6	0.33		181.5	0.33		1.68%	0.00%	
2	5	305.1	0.26		314	0.25		-2.92%	-3.85%	
2	4	227.4	0.31	0.302	224.6	0.31	0.303	1.23%	0.00%	0.33%
3	4	221.3	0.32		216.1	0.32		2.35%	0.00%	
3	3	198.6	0.3		192.6	0.31		3.02%	3.33%	
3	1	124.8	0.32		122.8	0.33		1.60%	3.13%	
3	2	156	0.32		145.8	0.34		6.54%	6.25%	
3	5	273.1	0.29	0.308	262.5	0.3	0.319	3.88%	3.45%	3.57%
4	4	242.2	0.29		233.8	0.3		3.47%	3.45%	
4	1	119.1	0.34		119.7	0.33		-0.50%	-2.94%	
4	5	257.4	0.31		250.6	0.32		2.64%	3.23%	
4	2	165	0.3		159.5	0.31		3.33%	3.33%	
4	3	181.5	0.33	0.311	176.9	0.34	0.319	2.53%	3.03%	2.57%
5	5	286.2	0.28		284.6	0.28		0.56%	0.00%	
5	4	214	0.33		208.7	0.34		2.48%	3.03%	
5	2	153.4	0.33		152	0.33		0.91%	0.00%	
5	3	203.5	0.29		198.6	0.3		2.41%	3.45%	
5	1	117.6	0.34	0.308	118	0.34	0.312	-0.34%	0.00%	1.30%
6	1	121.3	0.33		120.7	0.33		0.49%	0.00%	
6	2	150.4	0.33		148.5	0.34		1.26%	3.03%	
6	3	191	0.31		187.3	0.32		1.94%	3.23%	
6	4	252.9	0.28		245.9	0.28		2.77%	0.00%	
6	5	250.1	0.32	0.311	241.5	0.33	0.318	3.44%	3.13%	2.25%

Table 16. Comparison of Conventional and Normalized Calibration Strategies: Case With Undersizing and No Learning

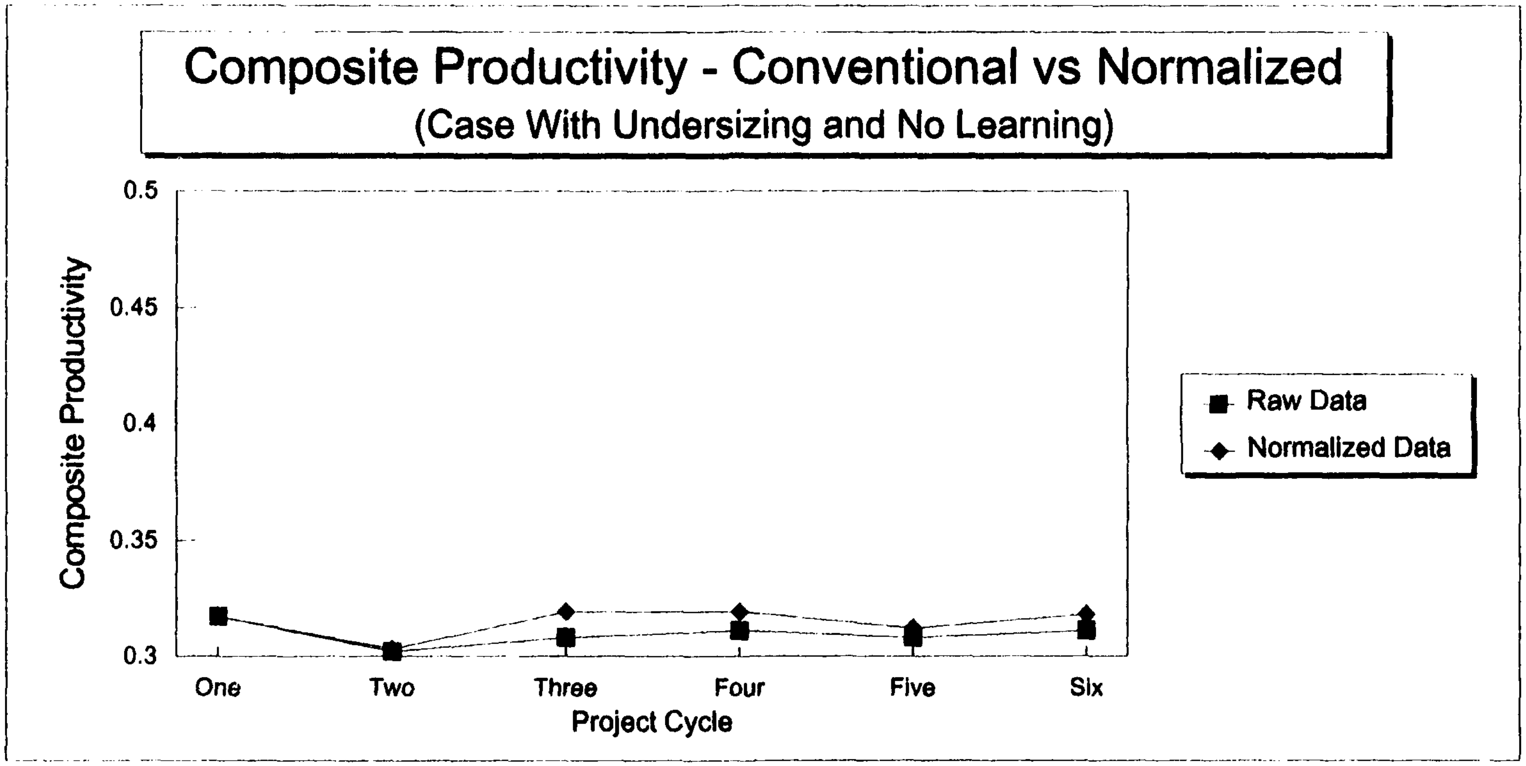

Figure 24. Composite Productivity: Conventional vs Normalized - Case With Undersizing and No Learning

E. THE EFFECTS OF OVERESTIMATION AND UNDERESTIMATION OF PRODUCTIVITY ON SIMULATION RESULTS

The final series of experiments examines the impact of overestimation / underestimation of productivity on project set results. In this scenario, we again assume undersizing and no learning, as in the previous experiment. However, this experiment explores the effect of misrepresenting productivity by virtue of how a "task" is defined.

Central to the notion of variable task definition is the situation where different software development organizations require different development efforts to design and code projects of a similar size and scope. Consequently, where DSI is constant and fixed in both organizations, the value of "task" becomes the determinant with regard to measuring effort.

First, the project set is re-simulated with underestimation and no learning, but with a DSIPTK value fixed at 75 percent of the nominal case. The nominal case default value of the SD simulator is "60", hence, the input metric is set at "45". Cost and productivity values are calculated in the usual manner, using both the conventional and normalization calibration strategies. Data and calculations are presented in Appendices J, K, and L, and are summarized in Table 17. A comparison with Table 16 values (undersizing, no learning, nominal DSIPTK value), and employing the conventional strategy with raw historical data, reveals significantly lower individual project productivities in each instance. Likewise, composite cycle productivities fall by 15.5 percent to 17.8 percent. The effects of normalization under these experimental conditions are negligible. Both individual

Cycle & Project		Raw Data: DSIPTK = 75%			Normalized: DSIPTK = 75%			Percent Improvement		
Cycle #	Project #	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod
1	1	221.8	0.28		221.8	0.28		0.00%	0.00%	
1	2	307.8	0.28		307.8	0.28		0.00%	0.00%	
1	3	289.8	0.27		289.8	0.27		0.00%	0.00%	
1	4	187.4	0.23		187.4	0.23		0.00%	0.00%	
1	5	138.1	0.28	0.262	138.1	0.28	0.262	0.00%	0.00%	0.00%
2	2	187.4	0.27		187.7	0.26		-0.16%	-3.70%	
2	1	138.1	0.29		137.6	0.29		0.36%	0.00%	
2	3	220.7	0.27		220	0.27		0.32%	0.00%	
2	5	370.4	0.22		370.7	0.22		-0.08%	0.00%	
2	4	272.7	0.26	0.252	252.4	0.25	0.252	7.44%	-3.85%	0.00%
3	4	265.8	0.26		264.9	0.26		0.34%	0.00%	
3	3	235.4	0.25		235.8	0.25		-0.17%	0.00%	
3	1	148.1	0.27		150	0.27		-1.28%	0.00%	
3	2	183.1	0.27		175.3	0.29		4.26%	7.41%	
3	5	323.5	0.25	0.26	324.9	0.25	0.261	-0.43%	0.00%	0.38%
4	4	284.8	0.25		285.2	0.25		-0.14%	0.00%	
4	1	143	0.28		142.4	0.28		0.42%	0.00%	
4	5	309.7	0.26		312	0.26		-0.74%	0.00%	
4	2	192.2	0.26		194.2	0.26		-1.04%	0.00%	
4	3	216	0.28	0.262	214.5	0.28	0.261	0.69%	0.00%	-0.38%
5	5	342.7	0.23		339.2	0.24		1.02%	4.35%	
5	4	264.3	0.26		256.7	0.27		2.88%	3.85%	
5	2	184.6	0.27		183.1	0.27		0.81%	0.00%	
5	3	243.4	0.25		241.6	0.25		0.76%	0.00%	
5	1	149.1	0.27	0.253	139.8	0.29	0.259	6.24%	7.41%	2.37%
6	1	145.7	0.27		146.2	0.27		-0.34%	0.00%	
6	2	178.7	0.28		178.5	0.28		0.11%	0.00%	
6	3	227.6	0.26		227.8	0.26		-0.09%	0.00%	
6	4	298.4	0.23		294.7	0.24		1.24%	4.35%	
6	5	300.9	0.27	0.261	301.7	0.27	0.261	-0.27%	0.00%	0.00%

Table 17. Comparison of Conventional and Normalized Calibration Strategies: Case With Undersizing, No Learning and DSIPTK = 75% of Nominal Case

project productivities and composite cycle productivities are virtually unchanged despite normalization (improvement range of -.38 percent to 2.37 percent).

Next, the DSIPTK value was set at 125 percent of the nominal case, or "75", and the projects re-simulated yet again with all other conditions unchanged. Supporting data and calculations are presented in Appendices M, N, and O, and are summarized in Table 18. Results under the conventional strategy reveal a global improvement in individual project productivity. Similarly, composite cycle productivity improves by an average of 10.34 percent over Table 16 (nominal) values. The effect of normalization in this scenario, while not as dramatic as under the learning assumption (Table 13), nevertheless improves composite productivity by an average of 11.96 percent over the Table 16 values, and yields an improvement over conventional strategy values ranging from 2.09 to 4.85 percent.

Figure 25 is a graphical representation of composite productivity under all exercise conditions described in this section, and includes data carried forward from the previous section (DSIPTK = 100%) for comparison purposes. The composite productivity positioning is readily apparent and appears directly linked to DSIPTK values/percentages. The figure also provides a view of the effects of normalization on each of the three data sets. Clearly, the higher DSIPTK values yield the more significant normalization benefit.

Cycle & Project		Raw Data: DSIPTK = 125%			Normalized: DSIPTK = 125%			Percent Improvement		
Cycle #	Project #	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod	MM (act)	Productivity	Comp.Prod
1	1	109.5	0.37		109.5	0.37		0.00%	0.00%	
1	2	138.2	0.36		138.2	0.36		0.00%	0.00%	
1	3	169	0.36		169	0.36		0.00%	0.00%	
1	4	230.9	0.3		230.9	0.3		0.00%	0.00%	
1	5	224.1	0.36	0.344	224.1	0.36	0.344	0.00%	0.00%	0.00%
2	2	140.2	0.36		140.1	0.36		0.07%	0.00%	
2	1	108.5	0.37		100.1	0.4		7.74%	8.11%	
2	3	164.2	0.37		164.1	0.37		0.06%	0.00%	
2	5	280.7	0.29		273	0.29		2.74%	0.00%	
2	4	202.4	0.35	0.335	199.3	0.35	0.342	1.53%	0.00%	2.09%
3	4	201	0.35		191.9	0.36		4.53%	2.86%	
3	3	175.8	0.34		172.5	0.35		1.88%	2.94%	
3	1	112.7	0.35		109	0.37		3.28%	5.71%	
3	2	142.5	0.35		128.7	0.39		9.68%	11.43%	
3	5	240	0.33	0.344	234.3	0.34	0.359	2.37%	3.03%	4.36%
4	4	218	0.32		205.8	0.34		5.60%	6.25%	
4	1	104.6	0.38		105.2	0.38		-0.57%	0.00%	
4	5	228.4	0.35		219.4	0.36		3.94%	2.86%	
4	2	146.7	0.34		138.7	0.36		5.45%	5.88%	
4	3	157.6	0.38	0.351	154.8	0.39	0.364	1.78%	2.63%	3.70%
5	5	256.7	0.31		257.3	0.31		-0.23%	0.00%	
5	4	206.3	0.34		186.7	0.37		9.50%	8.82%	
5	2	145.6	0.34		134.8	0.37		7.42%	8.82%	
5	3	183.9	0.33		184.5	0.33		-0.33%	0.00%	
5	1	115.8	0.35	0.33	102.8	0.39	0.346	11.23%	11.43%	4.85%
6	1	109.3	0.37		106.8	0.37		2.29%	0.00%	
6	2	137.7	0.36		133.6	0.37		2.98%	2.78%	
6	3	168.8	0.36		165.6	0.36		1.90%	0.00%	
6	4	231.3	0.3		217.7	0.32		5.88%	6.67%	
6	5	223	0.36	0.345	212.2	0.38	0.359	4.84%	5.56%	4.06%

Table 18. Comparison of Conventional and Normalized Calibration Strategies: Case With Undersizing, No Learning and DSIPTK = 125% of Nominal Case

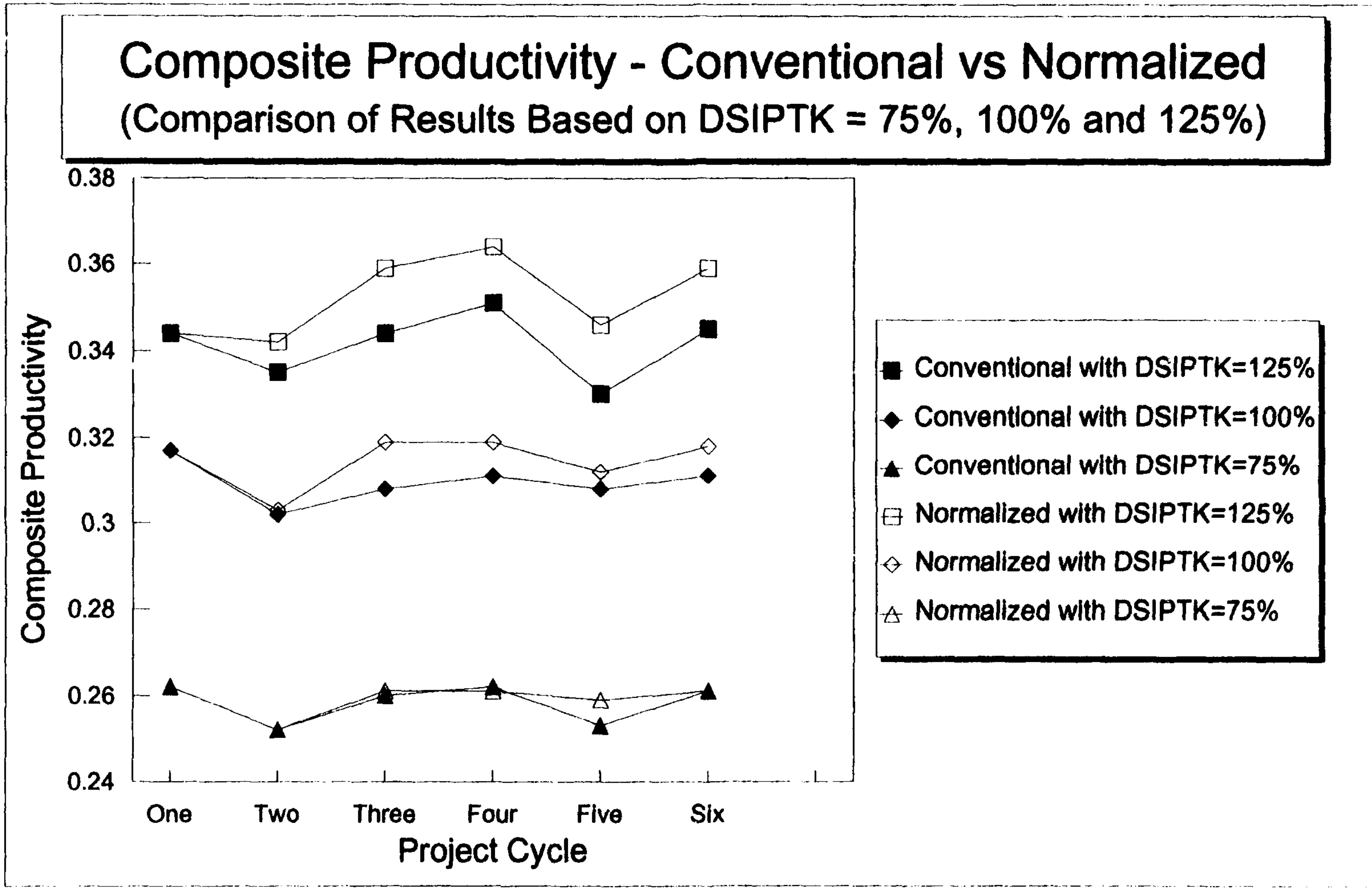

Figure 25. Composite Productivity: Conventional vs Normalized DSIPTK = 75%, 100%, and 125%

V. CONCLUSIONS

A. SUMMARY OF FINDINGS AND IMPLICATIONS

The major objective of this thesis was to use simulation modeling to replicate the development of a set of 30 hypothetical software projects, the results of which were used to evaluate two competing calibration strategies for the COCOMO software estimation tool in four experimental scenarios.

1. Phase One

In phase one, the simulated project costs obtained by applying the conventional calibration strategy, were evaluated against a similar set of cost values obtained by applying the normalized calibration strategy in a scenario which assumed both learning and undersizing. The normalization process contributed to significant increases in both individual project productivity and composite cycle productivity. The experiment demonstrated that normalization provided the organization with more optimal calibration coefficients which, in turn, lead to more optimal cost estimations. As inefficiencies were eliminated in project cost estimation, simulations produced projects with lower actual costs, and hence, improved productivity.

The experiment also demonstrated that the normalization strategy provided the software organization with the *potential* for significant future cost savings. The normalization process effectively removed many of the inefficiencies associated with undersized projects. Consequently, archiving normalized cost data in the organizational data base vice the actual project results, produced more optimal estimates when identical projects were re-simulated following model calibration. In contrast, as a result of higher calibration coefficients, the conventional calibration strategy produced consistently larger and less optimal cost estimates.

Post-facto knowledge of the projects' actual size was used to calculate two related exercise metrics, both of which provided an indication of the relative accuracy and validity of the software estimation tool -- estimated productivity and relative error in cost estimation. The normalized cost data produced the strongest correlation between actual and estimated productivity results, indicating that the model provided more accurate estimates. This was confirmed when the computed accuracy of the base case COCOMO estimates clearly favored the normalized calibration model.

2. Phase Two

In phase two, the base case results of phase one were compared with simulated results of a new case assuming learning, but no undersizing. With no undersizing, both the conventional and normalized calibration strategies produced global improvements in project productivities over base case results. Normalization again provided cost benefit over raw historical data, but in this scenario, the average improvement in individual project productivity was less dramatic than in the base case. Similarly, composite cycle productivities were only marginally improved over their base case counterparts. These findings suggest that normalization may be an effective strategy to counterbalance the detrimental effects of initial project undersizing. Both estimated productivity and relative accuracy solutions in this scenario revealed that the conventional calibration strategy produced increasingly suboptimal model performance over the six project cycles. Conversely, the normalized model continued to provide extremely precise estimates throughout all project cycles.

3. Phase Three

Phase three re-simulated the project set in a scenario which included project size underestimation, but no learning. Normalization was least effective in this scenario, yielding minimal improvement, at best, over the conventional strategy in all key cost and productivity metrics. The findings suggest that without learning, both the conventional and normalization calibration strategies are largely ineffective in improving productivity. A comparison of relative model accuracy was also inconclusive in this scenario.

4. Phase Four

The final phase of the experiment investigated the impact of both underestimation and overestimation of productivity on the results of the phase three experiment. First, with productivity underestimated by a factor of 75 percent of the nominal case, all productivity metrics were degraded, and normalization had a negligible impact. Next, with productivity overestimated by a factor of 125 percent of the nominal case, all productivity values showed improvement. Normalization was again effective in this scenario, but less dramatically than in the base case (learning and no undersizing). Productivity in this scenario appears directly linked to the concept of variable task definition as it relates to the number of delivered source instructions per task (DSIPTK). In addition, the effects of normalization also tend to follow this DSIPTK movement – the higher DSIPTK values yield the more significant normalization benefit.

B. FURTHER RESEARCH RECOMMENDATIONS

Three interesting research directions could be pursued as follow-on to this study. The first possibility is a validation of the findings of this simulation-based study by conducting an experiment in a real organization to compare the two strategies. Second, the current normalization strategy seeks to eliminate the inefficiencies caused by undersizing. The SD simulator could be used to examine the possibilities of eliminating other sources of inefficiency such as the misallocation of staff resources. Third, the normalization process requires repeated simulations to arrive at the optimal cost solution, and as such, is quite labor and time-intensive. The possibility for automating the process, perhaps employing artificial intelligence techniques, could be investigated.

APPENDIX A. CONVENTIONAL CALIBRATION STRATEGY: BASE CASE

CYCLE #1(Raw Data)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	100	40	40	24	67.5	12.4		120.9	18.5
2	100	50	20	40	115.4	15.2		149.7	18.6
3	100	60	30	42	121.5	15.5		187.6	19.9
4	100	70	50	35	100.3	14.4		245.8	21.9
5	100	80	10	72	214	19.2		242.3	22.3

Proj.Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	120.9	48	5803	5803	2304	2304		0.33	
2	50	145.9	149.7	61	9132	14935	3721	6025		0.33	
3	60	176.7	187.6	74	13882	28817	5476	11501		0.32	
4	70	207.8	245.8	87	21385	50202	7569	19070		0.28	
5	80	239	242.3	100	24230	74432	10000	29070	2.56	0.33	0.317

CYCLE #2 (Raw Data)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
2	120	50	40	30	91	13.9		147.3	17.8
1	120	40	10	36	110.2	14.9		117.7	16.6
3	120	60	20	48	149.1	16.7		178.6	18.6
5	120	80	50	40	123.1	15.6		291.4	21.1
4	120	70	30	49	152.4	16.9		209.9	19.3

Proj.Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	155.7	147.3	61	8985	8985	3721	3721		0.34	
1	40	123.1	117.7	48	5650	14635	2304	6025		0.34	
3	60	188.5	178.6	74	13216	27851	5476	11501		0.34	
5	80	255	291.4	100	29140	56991	10000	21501		0.27	
4	70	221.6	209.9	87	18261	75252	7569	29070	2.59	0.33	0.317

CYCLE #3 (Raw Data)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	140	70	20	56	177.4	17.9		216.5	19.5
3	140	60	40	36	111.5	15		189.2	18.2
1	140	40	50	20	60.2	11.9		123.1	17.4
2	140	50	10	45	141	16.4		147	17.4
5	140	80	30	56	177.4	17.9		251.2	19.8

Proj.Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	224.2	216.5	87	18836	18836	7569	7569		0.32	
3	60	190.7	189.2	74	14001	32837	5476	13045		0.32	
1	40	124.6	123.1	48	5909	38746	2304	15349		0.32	
2	50	157.5	147	61	8967	47713	3721	19070		0.34	
5	80	258	251.2	100	25120	72833	10000	29070	2.51	0.32	0.324

CYCLE #4 (Raw Data)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	160	70	40	42	127.1	15.8		212.1	18.2
1	160	40	30	28	83	13.4		111.1	16
5	160	80	20	64	197.8	18.6		233.8	19.5
2	160	50	50	25	73.7	12.8		146.9	17.2
3	160	60	10	54	166.5	17.4		165.7	17.9

Proj.Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	217.3	212.1	87	18453	18453	7569	7569		0.33	
1	40	120.7	111.1	48	5333	23786	2304	9873		0.36	
5	80	250	233.8	100	23380	47166	10000	19873		0.34	
2	50	152.6	146.9	61	8961	56127	3721	23594		0.34	
3	60	184.8	165.7	74	12262	68389	5476	29070	2.35	0.36	0.345

CYCLE #5 (Raw Data)

Proj.Sizes	DISP1K (%)	KOH (gal)	Under (%)	KOH (gal)	MM (gal)	TDEV (gal)		MM (gal)	TDEV (gal)
5	180	80	40	48	138.9	18.2		225.9	18.2
4	180	70	10	63	182.1	18.1	→	180	18.6
2	180	50	30	36	88.3	14.3		130.8	16.4
3	180	60	50	30	83.6	13.4	→	165.3	17.2
1	180	40	20	32	80.4	13.8		100.5	15.5

Proj.Sizes	KOH (gal)	MM (gal)	MM(adjusted)	Q	MM(adj)*Q	sum MM(adj)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	234.1	225.9	100	22590	22590	10000	10000		0.35	
4	70	203.4	180	87	15660	38250	7569	17569		0.39	
2	50	142.9	130.8	61	7987	46217	3721	21290		0.38	
3	60	173	165.3	74	12232	58449	5476	26766		0.38	
1	40	113	100.5	48	4824	63273	2304	29070	2.18	0.4	0.374

CYCLE #6 (Raw Data)

Proj.Sizes	DISP1K (%)	KOH (gal)	Under (%)	KOH (gal)	MM (gal)	TDEV (gal)		MM (gal)	TDEV (gal)
1	200	40	40	24	61.3	11.9		98.3	15.7
2	200	50	20	40	104.9	14.8	→	117.2	15.9
3	200	60	30	42	110.4	14.9		146.8	16.8
4	200	70	50	36	91.1	13.9	→	180.5	17.3
5	200	80	10	72	184.4	18.5		191.7	18.2

Proj.Sizes	KOH (gal)	MM (gal)	MM(adjusted)	Q	MM(adj)*Q	sum MM(adj)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	104.9	98.3	48	4674	4674	2304	2304		0.42	
2	50	132.5	117.2	61	7149	11723	3721	6025		0.43	
3	60	180.5	145.8	74	10789	22512	5476	11501		0.41	
4	70	188.7	180.5	87	15704	38216	7569	19070		0.39	
5	80	217.1	191.7	100	19170	57386	10000	29070	1.97	0.42	0.411

APPENDIX B. NORMALIZATION DATA: BASE CASE

CYCLE #1, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18.5	120.9	120.6
40	18.5	115	115.3
40	18.5	110	114.6
40	18.5	105	113.4
40	18.5	100	112.7
40	18.5	95	[illegible]
40	18.5	90	112.7
40	18.5	85	113.3
40	18.5	80	115.4

CYCLE #1, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	18.6	149.7	149.4
50	18.6	145	146.2
50	18.6	140	145.9
50	18.6	135	143.8
50	18.6	130	143.1
50	18.6	125	142.9
50	18.6	120	142.6
50	18.6	118	[illegible]
50	18.6	115	142.6

CYCLE #1, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.9	187.6	187.3
60	19.9	180	180.1
60	19.9	170	176.9
60	19.9	160	174.4
60	19.9	155	173.2
60	19.9	150	173
60	19.9	145	[illegible]
60	19.9	140	173.4
60	19.9	135	174.3

CYCLE #1, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	21.9	245.8	243.7
70	21.9	235	234.1
70	21.9	220	219.6
70	21.9	210	212.3
70	21.9	200	207.9
70	21.9	190	205.3
70	21.9	185	[illegible]
70	21.9	175	204.7
70	21.9	170	205.3

CYCLE #1, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	22.3	242.3	246.7
80	22.3	235	242
80	22.3	225	238.8
80	22.3	220	237.6
80	22.3	215	236.6
80	22.3	210	236.5
80	22.3	205	[illegible]
80	22.3	200	237.2
80	22.3	195	238.2

CYCLE #2, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	18.3	142.7	142.3
50	18.3	130	131.3
50	18.3	120	130.4
50	18.3	115	128.9
50	18.3	110	128.4
50	18.3	105	[illegible]
50	18.3	100	128.7
50	18.3	95	130

CYCLE #2, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	16.3	107.6	107.2
40	16.3	100	102.5
40	16.3	90	102.2
40	16.3	85	101.2
40	16.3	80	[illegible]
40	16.3	75	101.7
40	16.3	70	103.3

CYCLE #2, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	18.6	165.9	165.5
60	18.6	150	159.5
60	18.6	135	155.9
60	18.6	130	[illegible]
60	18.6	125	155.7
60	18.6	120	156.8
60	18.6	110	161.1

CYCLE #2, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	21.4	277.9	269.6
80	21.4	240	239.3
80	21.4	210	218.5
80	21.4	190	213.4
80	21.4	185	[redacted]
80	21.4	180	213.3
80	21.4	175	213.8
80	21.4	170	215.5

CYCLE #2, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	19.8	207.7	207.3
70	19.8	170	185.5
70	19.8	160	184.2
70	19.8	155	[redacted]
70	19.8	150	184.5
70	19.8	140	186.8

CYCLE #3, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	19.2	182.1	181.5
70	19.2	150	169.8
70	19.2	145	169.2
70	19.2	140	169.3
70	19.2	137.5	[redacted]
70	19.2	135	169.3
70	19.2	130	170.5

CYCLE #3, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	18.9	164.8	164.2
60	18.9	130	144.6
60	18.9	125	143.5
60	18.9	120	[redacted]
60	18.9	115	143.7
60	18.9	110	144.5

CYCLE #3, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18.3	104.6	104.3
40	18.3	80	93.5
40	18.3	77.5	93.6
40	18.3	75	[redacted]
40	18.3	72.5	94.2
40	18.3	70	95.1
40	18.3	60	98.4

CYCLE #3, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	16.9	122.7	122.5
50	16.9	100	117.8
50	16.9	95	[redacted]
50	16.9	90	117.9
50	16.9	60	129.8

CYCLE #3, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	20.4	229.9	228.8
80	20.4	200	202.7
80	20.4	180	197.8
80	20.4	170	195.6
80	20.4	167.5	[redacted]
80	20.4	165	195.4
80	20.4	162.5	196
80	20.4	160	196.6
80	20.4	130	202.7

CYCLE #4, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	19.4	188	185.6
70	19.4	160	162.8
70	19.4	140	158.8
70	19.4	135	157.9
70	19.4	132.5	[redacted]
70	19.4	130	157.5
70	19.4	125	158.4
70	19.4	120	159.8

CYCLE #4, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	16.4	92.3	92
40	16.4	70	86.9
40	16.4	67.5	86.5
40	16.4	65	[redacted]
40	16.4	60	88.6
40	16.4	50	94.6

CYCLE #4, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	19.8	199.9	199.1
80	19.8	170	185.4
80	19.8	160	182.9
80	19.8	157.5	182.3
80	19.8	155	[redacted]
80	19.8	150	182.3
80	19.8	145	183.3
80	19.8	140	184.3
80	19.8	135	186.7

CYCLE #4, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	18.7	128	127.4
50	18.7	100	111.8
50	18.7	95	110.6
50	18.7	90	[redacted]
50	18.7	85	110.9
50	18.7	80	113.1

CYCLE #4, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	17.6	138.5	138.2
60	17.6	115	133.8
60	17.6	110	133.2
60	17.6	107.5	[redacted]
60	17.6	105	133.2
60	17.6	100	133.7
60	17.6	85	141.3

CYCLE #5, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	19.9	215.1	201
80	19.9	185	184.3
80	19.9	155	173.6
80	19.9	145	171.8
80	19.9	142.5	[redacted]
80	19.9	140	171.8
80	19.9	130	174.4

CYCLE #5, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	18.3	154.4	153.9
70	18.3	130	149.3
70	18.3	120	[redacted]
70	18.3	110	149.7

CYCLE #5, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	16.9	111.6	111.1
50	16.9	100	106.1
50	16.9	90	104.6
50	16.9	85	103.7
50	16.9	80	[redacted]
50	16.9	75	103.8
50	16.9	70	106.8

CYCLE #5, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.1	151.9	144.8
60	19.1	120	128.9
60	19.1	110	126.8
60	19.1	105	[redacted]
60	19.1	100	126.2
60	19.1	95	128
60	19.1	90	130.1
60	19.1	80	132.4

CYCLE #5, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	15.5	85.1	84.9
40	15.5	70	82.5
40	15.5	65	81.5
40	15.5	62.5	81
40	15.5	60	[redacted]
40	15.5	55	82.9
40	15.5	50	86.4

APPENDIX C. NORMALIZATION CALIBRATION STRATEGY: BASE CASE

CYCLE #1(Raw Data)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	100	40	40	24	67.5	12.4		120.9	18.5
2	100	50	20	40	115.4	15.2	→	149.7	18.6
3	100	60	30	42	121.5	15.5		187.6	19.9
4	100	70	50	35	100.3	14.4	→	245.8	21.9
5	100	80	10	72	214	19.2		242.3	22.3

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	120.9	112.6	48	5405	5405	2304	2304		0.33	
2	50	145.9	149.7	142.5	61	8693	14098	3721	6025		0.33	
3	60	176.7	187.6	172.8	74	12787	26885	5476	11501		0.32	
4	70	207.8	245.8	204.4	87	17783	44668	7569	19070		0.28	
5	80	239	242.3	236.4	100	23640	68308	10000	29070	2.35	0.33	0.317

CYCLE #2 (Normalized Data)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
2	120	50	40	30	83.6	13.4		142.7	18.3
1	120	40	10	36	101.2	14.5	→	107.6	18.3
3	120	60	20	48	136.9	16.2		165.9	18.6
5	120	80	50	40	113	15.1	→	277.9	21.4
4	120	70	30	49	139.9	16.3		207.7	19.8

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	142.9	142.7	128.2	61	7820	7820	3721	3721		0.36	
1	40	113	107.6	100.9	48	4843	12663	2304	6025		0.37	
3	60	173	165.9	155.6	74	11514	24177	5476	11501		0.36	
5	80	234.1	277.9	212.7	100	21270	45447	10000	21501		0.29	
4	70	203.4	207.7	183.6	87	15991	61438	7569	29070	2.11	0.34	0.339

CYCLE #3 (Normalized Data)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	140	70	20	55	144.5	16.5		182.1	19.2
3	140	60	40	36	90.9	13.9	→	164.8	18.9
1	140	40	80	20	49	11		104.6	18.3
2	140	50	10	45	114.9	15.2	→	122.7	18.9
5	140	80	30	56	144.6	16.5		229.9	20.4

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	182.7	182.1	169	87	14763	14763	7569	7569		0.38	
3	60	156.4	164.8	142.8	74	10507	25270	5476	13045		0.38	
1	40	101.5	104.6	95.4	48	4483	29753	2304	15349		0.38	
2	50	128.3	122.7	117.3	61	7155	36908	3721	19070		0.41	
5	80	210.1	229.9	196.5	100	19580	56488	10000	29070	1.94	0.36	0.373

CYCLE #4 (Normalized Data)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	160	70	40	42	98.2	14.3		186	19.4
1	160	40	30	28	64.2	12.2	→	92.3	16.4
5	160	80	20	64	152.9	16.9		199.9	19.8
2	160	50	50	25	57	11.6	→	128	18.7
3	160	60	10	54	127.9	16.6		138.5	17.6

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	167.9	186	157.4	87	13694	13694	7569	7569		0.37	
1	40	98.3	92.3	86.4	48	4147	17841	2304	9873		0.43	
5	80	193.2	199.9	182	100	18200	36041	10000	19873		0.4	
2	50	116	128	110.1	61	6716	42757	3721	23594		0.39	
3	60	142.8	138.5	132.6	74	9812	52569	5476	29070	1.81	0.43	0.402

CYCLE #5 (Normalized Data)									
Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
5	180	80	40	48	105.4	14.7		215.1	19.9
4	180	70	10	63	140.3	16.4	→	154.4	18.3
2	180	50	30	36	75.7	12.9		111.6	16.9
3	180	60	50	30	64.4	12.2	→	151.9	19.1
1	180	40	20	32	68.9	12.5		86.1	15.5

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	180.3	215.1	171.5	100	17150	17150	10000	10000		0.37	
4	70	158.7	154.4	147.6	87	12841	29991	7569	17569		0.45	
2	50	110.1	111.6	102.9	61	6277	36268	3721	21290		0.45	
3	60	133.3	151.9	126.1	74	9331	45599	5476	26766		0.39	
1	40	87.1	86.1	81	48	3888	49487	2304	29070	1.7	0.47	0.418

CYCLE #6 (Normalized Data)									
Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	200	40	40	24	47.8	10.9		84.1	16.7
2	200	50	20	40	81.8	13.3	→	103.2	16.2
3	200	60	30	42	86.1	13.6		130.9	17.5
4	200	70	50	35	71.1	12.6	→	176.6	19.5
5	200	80	10	72	151.6	16.9		170	9

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	81.8	84.1		48	0	0	2304	2304		0.48	
2	50	103.4	103.2		61	0	0	3721	6025		0.48	
3	60	125.2	130.9		74	0	0	5476	11501		0.46	
4	70	147.2	176.6		87	0	0	7569	19070		0.4	
5	80	169.3	170		100	0	0	10000	29070	0	0.47	0.451

APPENDIX D. CONVENTIONAL CALIBRATION STRATEGY: LEARNING - NO UNDERSIZING

CYCLE #1 (Raw Data, 100% DSIPTK, NO UNDERSIZING)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	100	40	0	40	115.4	15.2		115.4	16.5
2	100	50	0	50	145.9	16.6		146.9	17.9
3	100	60	0	60	176.7	17.9		178.3	19.4
4	100	70	0	70	207.8	19		212	20.7
5	100	80	0	80	239	20		246.7	21.9

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	115.4	48	5539	5539	2304	2304		0.35	
2	50	145.9	146.9	61	8900	14439	3721	6025		0.34	
3	60	176.7	178.3	74	13194	27633	5476	11501		0.34	
4	70	207.8	212	87	18444	46077	7569	19070		0.33	
5	80	239	246.7	100	24670	70747	10000	29070	2.43	0.32	0.334

CYCLE #2 (Raw Data, 120% DSIPTK, NO UNDERSIZING)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
2	120	50	0	50	147.7	16.7		147.3	17.9
1	120	40	0	40	116.9	15.3		116.6	16.6
3	120	60	0	60	178.9	17.9		178.2	19.1
5	120	80	0	80	242	20.1		241.2	21.3
4	120	70	0	70	210.4	19.1		209.7	20.3

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	147.7	147.3	61	8985	8985	3721	3721		0.34	
1	40	116.9	116.6	48	5597	14582	2304	6025		0.34	
3	60	178.9	178.2	74	13187	27769	5476	11501		0.34	
5	80	242	241.2	100	24120	51889	10000	21501		0.33	
4	70	210.4	209.7	87	18244	70133	7569	29070	2.41	0.33	0.336

CYCLE #3 (Raw Data, 140% DSIPTK, NO UNDERSIZING)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	140	70	0	70	208.6	19		206.1	20.1
3	140	60	0	60	177.4	17.9		174.4	18.9
1	140	40	0	40	115.9	15.2		112.7	16.1
2	140	50	0	50	146.5	16.6		143.2	17.5
5	140	80	0	80	240	20.1		237.4	21.2

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	208.6	206.1	87	17931	17931	7569	7569		0.34	
3	60	177.4	174.4	74	12906	30837	5476	13045		0.34	
1	40	115.9	112.7	48	5410	36247	2304	15349		0.35	
2	50	146.5	143.2	61	8735	44982	3721	19070		0.35	
5	80	240	237.4	100	237[illegible]0	68722	10000	29070	2.38	0.34	0.343

CYCLE #4 (Raw Data, 160% DSIPTK, NO UNDERSIZING)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	160	70	0	70	204.3	18.9		191.2	19.4
1	160	40	0	40	113.5	15.1		104.2	15.7
5	160	80	0	80	235	19.9		222.6	19.7
2	160	50	0	50	143.5	16.5		132.4	17
3	160	60	0	60	173.8	17.7		161.4	18.2

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	204.3	191.2	87	16634	16634	7569	7569		0.37	
1	40	113.5	104.2	48	5002	21636	2304	9873		0.38	
5	80	235	222.6	100	22260	43896	10000	19873		0.38	
2	50	143.5	132.4	61	8076	51972	3721	23594		0.38	
3	60	173.8	161.4	74	11944	63916	5476	29070	2.2	0.37	0.37

CYCLE #5 (Raw Data, 180% DSIPTK, NO UNDERSIZING)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
5	180	80	0	80	219.1	19.4	202.5	20.1
4	180	70	0	70	190.4	18.4	174.8	19
2	180	50	0	50	133.8	16.1	121.5	16.6
3	180	60	0	60	162	17.3	148	17.8
1	180	40	0	40	105.8	14.7	95.6	15.3

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	219.1	202.5	100	20250	20250	10000	10000		0.4	
4	70	190.4	174.8	87	15208	35458	7569	17569		0.4	
2	50	133.8	121.5	61	7412	42870	3721	21290		0.41	
3	60	162	148	74	10952	53822	5476	26766		0.41	
1	40	105.8	95.6	48	4589	58411	2304	29070	2.01	0.42	0.404

CYCLE #6 (Raw Data, 200% DSIPTK, NO UNDERSIZING)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1	200	40	0	40	96.7	14.2	87.7	14.9
2	200	50	0	50	122.2	15.5	111.4	16.2
3	200	60	0	60	148	16.7	135.3	17.3
4	200	70	0	70	174	17.8	159.7	18.5
5	200	80	0	80	200.2	18.7	184.6	19.4

Proj.Serial	KDSI (act)	MM (est)	MM(actual)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	96.7	87.7	48	4210	4210	2304	2304		0.46	
2	50	122.2	111.4	61	6795	11005	3721	6025		0.45	
3	60	148	135.3	74	10012	21017	5476	11501		0.44	
4	70	174	159.7	87	13894	34911	7569	19070		0.44	
5	80	200.2	184.6	100	18460	53371	10000	29070	1.84	0.43	0.442

APPENDIX E. NORMALIZATION CALIBRATION STRATEGY: LEARNING - NO UNDERSIZING

CYCLE #1 (Normalized Data, 100% DSIPTK, NO UNDERSIZING))

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1	100	40	0	40	115.4	15.2	115.4	16.5
2	100	50	0	50	145.9	16.6	145.9	17.9
3	100	60	0	60	176.7	17.9	178.3	19.4
4	100	70	0	70	207.8	19	212	20.7
5	100	80	0	80	239	20	246.7	21.9

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(norm)*Q	sum MM(norm)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	115.4	112.8	48	5414	5414	2304	2304		0.35	
2	50	145.9	145.9	142.4	61	8686	14100	3721	6025		0.34	
3	60	176.7	178.3	172.8	74	12787	26887	5476	11501		0.34	
4	70	207.8	212	204.3	87	17774	44661	7569	19070		0.33	
5	80	239	246.7	236.5	100	23650	68311	10000	29070	2.35	0.32	0.334

CYCLE #2 (Normalized Data, 120% DSIPTK, NO UNDERSIZING)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
2	120	50	0	50	142.9	16.5	142.4	17.7
1	120	40	0	40	113	15.1	112.6	16.4
3	120	60	0	60	173	17.7	172.6	18.9
5	120	80	0	80	234.1	19.9	233.7	21.2
4	120	70	0	70	203.4	18.8	203.1	20.1

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(norm)*Q	sum MM(norm)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	142.9	142.4	127.9	61	7802	7802	3721	3721		0.35	
1	40	113	112.6	101.2	48	4858	12660	2304	6025		0.36	
3	60	173	172.6	155.6	74	11514	24174	5476	11501		0.35	
5	80	234.1	233.7	212.9	100	21290	45464	10000	21501		0.34	
4	70	203.4	203.1	183.9	87	15999	61463	7569	29070	2.11	0.34	0.347

CYCLE #3 (Normalized Data, 140% DSIPTK, NO UNDERSIZING))

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	140	70	0	70	182.7	18.1	182.1	19.3
3	140	60	0	60	155.4	17	154.7	18.2
1	140	40	0	40	101.5	14.5	101.4	15.8
2	140	50	0	50	128.3	15.8	127.9	17.1
5	140	80	0	80	210.1	19.1	209.4	20.3

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(norm)*Q	sum MM(norm)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	182.7	182.1	168.8	87	14686	14686	7569	7569		0.38	
3	60	155.4	154.7	142.8	74	10567	25253	5476	13045		0.39	
1	40	101.5	101.4	92.7	48	4450	29703	2304	15349		0.39	
2	50	128.3	127.9	117.1	61	7143	36846	3721	19070		0.39	
5	80	210.1	209.4	195.6	100	19560	56406	10000	29070	1.94	0.38	0.387

CYCLE #4 (Normalized Data, 160% DSIPTK, NO UNDERSIZING))

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	160	70	0	70	167.9	17.5	167.5	18.7
1	160	40	0	40	93.3	14	93.1	15.4
5	160	80	0	80	193.2	18.5	192.7	19.7
2	160	50	0	50	118	15.3	117.7	16.6
3	160	60	0	60	142.8	16.5	142.3	17.7

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(norm)*Q	sum MM(norm)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	167.9	167.5	157	87	13659	13659	7569	7569		0.42	
1	40	93.3	93.1	86.4	48	4147	17806	2304	9873		0.43	
5	80	193.2	192.7	182.2	100	18220	36026	10000	19873		0.42	
2	50	118	117.7	109	61	6649	42675	3721	23594		0.42	
3	60	142.8	142.3	132.9	74	9835	52510	5476	29070	1.81	0.42	0.421

CYCLE #5 (Normalized Data 180% DSIPTK, NO UNDERSIZING))

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
5	180	80	0	80	180.3	18	179.6	19.2
4	180	70	0	70	156.7	17.1	156.1	18.3
2	180	50	0	50	110.1	14.9	109.6	16.2
3	180	60	0	60	133.3	16	133	17.3
1	180	40	0	40	87.1	13.7	86.7	15.1

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(norm)*Q	sum MM(norm)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	180.3	179.6	171.3	100	17130	17130	10000	10000		0.45	
4	70	156.7	156.1	147.6	87	12841	29971	7569	17569		0.45	
2	50	110.1	109.6	102.5	61	6253	36224	3721	21290		0.46	
3	60	133.3	133	124.4	74	9206	45430	5476	26766		0.45	
1	40	87.1	86.7	80.7	48	3874	49304	2304	29070	1.7	0.46	0.451

CYCLE #6 (Normalized Data 200% DSIPTK, NO UNDERSIZING))

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1	200	40	0	40	81.8	13.3	81.4	14.7
2	200	50	0	50	103.4	14.6	103	15.9
3	200	60	0	60	125.2	15.7	124.7	16.9
4	200	70	0	70	147.2	16.7	146.8	17.9
5	200	80	0	80	169.3	17.6	168.5	18.8

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(norm)*Q	sum MM(norm)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	81.8	81.4	*	48	0	0	2304	2304		0.49	
2	50	103.4	103	*	61	0	0	3721	6025		0.49	
3	60	125.2	124.7	*	74	0	0	5476	11501		0.48	
4	70	147.2	146.8	*	87	0	0	7569	19070		0.48	
5	80	169.3	168.5	*	100	0	0	10000	29070	*	0.47	0.48

APPENDIX F. NORMALIZATION DATA
LEARNING - NO UNDERSIZING

CYCLE #1, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	16.5	115.4	115.3
40	16.5	110	114.2
40	16.5	105	114
40	16.5	100	112.9
40	16.5	95	112.8
40	16.5	90	112.9
40	16.5	85	112.9
40	16.5	80	113.6

CYCLE #1, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	17.9	145.9	146.4
50	17.9	135	144.1
50	17.9	125	143.1
50	17.9	120	142.6
50	17.9	115	142.4
50	17.9	110	143.1
50	17.9	105	143.5

CYCLE #1, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.9	178.3	178.8
60	19.9	155	173.2
60	19.9	150	173
60	19.9	145	172.8
60	19.9	140	173.4
60	19.9	135	174.3

CYCLE #1, PROJECT #4

KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	20.7	212	212.5
70	20.7	190	205.9
70	20.7	180	204.5
70	20.7	175	204.3
70	20.7	170	204.6
70	20.7	165	205.3
70	20.7	160	205.8

CYCLE #1, PROJECT #5

KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	21.9	246.7	247.8
80	21.9	220	237.8
80	21.9	215	236.9
80	21.9	210	236.5
80	21.9	205	236.7
80	21.9	200	237
80	21.9	195	237.8
80	21.9	190	238.6

CYCLE #2, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	17.7	142.4	142.1
50	17.7	130	131.2
50	17.7	120	130.3
50	17.7	115	128.9
50	17.7	110	128.2
50	17.7	105	128.2
50	17.7	102.5	127.9
50	17.7	100	128.5
50	17.7	95	

CYCLE #2, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	16.4	112.6	112.2
40	16.4	100	102.9
40	16.4	90	102.1
40	16.4	85	101.6
40	16.4	80	101.2
40	16.4	75	101.9
40	16.4	70	103.5

CYCLE #2, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	18.9	172.6	172.3
60	18.9	150	159.4
60	18.9	135	156
60	18.9	132.5	155.6
60	18.9	130	155.6
60	18.9	127.5	155.6
60	18.9	125	155.6
60	18.9	120	157.1
60	18.9	110	161.9

CYCLE #2, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	21.2	233.7	232.9
80	21.2	210	218.5
80	21.2	190	213.6
80	21.2	185	213
80	21.2	180	212.9
80	21.2	177.5	213.5
80	21.2	175	213.4
80	21.2	170	215.3

CYCLE #2, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	20.1	203.1	202.4
70	20.1	180	188.3
70	20.1	160	184.4
70	20.1	155	183.9
70	20.1	150	184.5
70	20.1	145	185.6

CYCLE #3, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	19.3	182.1	181.6
70	19.3	160	172.6
70	19.3	145	169.1
70	19.3	142.5	168.8
70	19.3	140	169.1
70	19.3	135	169.7
70	19.3	130	170.9

CYCLE #3, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	18.2	154.7	154.2
60	18.2	135	146.4
60	18.2	125	143.8
60	18.2	120	142.8
60	18.2	115	142.9
60	18.2	110	144
60	18.2	105	145.6

CYCLE #3, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	15.8	101.4	101.1
40	15.8	90	94.4
40	15.8	80	93.4
40	15.8	75	93.1
40	15.8	70	92.7
40	15.8	65	93.9
40	15.8	60	97

CYCLE #3, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	17.1	127.9	127.4
50	17.1	100	118.1
50	17.1	95	117.5
50	17.1	92.5	117.1
50	17.1	90	117.9
50	17.1	85	119.8
50	17.1	80	122.4

CYCLE #3, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	20.3	209.4	208.8
80	20.3	180	197.9
80	20.3	170	195.7
80	20.3	167.5	195.7
80	20.3	165	195.6
80	20.3	160	196.1
80	20.3	155	197.3
80	20.3	150	199.2

CYCLE #4, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	18.7	167.5	167.2
70	18.7	150	161.6
70	18.7	135	157.8
70	18.7	132.5	157.4
70	18.7	130	157
70	18.7	127.5	157.3
70	18.7	125	157.5

CYCLE #4, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	15.4	93.1	92.9
40	15.4	80	88
40	15.4	75	88.1
40	15.4	70	86.5
40	15.4	65	86.4
40	15.4	60	86.9

CYCLE #4, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	19.7	192.7	191.9
80	19.7	170	185.5
80	19.7	160	183.1
80	19.7	155	182.2
80	19.7	150	182.5
80	19.7	145	182.9
80	19.7	140	184.7

CYCLE #4, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	16.6	117.7	117.4
50	16.6	100	112.3
50	16.6	90	109.8
50	16.6	87.5	109.4
50	16.6	85	109
50	16.6	82.5	109.7
50	16.6	80	109.9

CYCLE #4, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	17.7	142.3	142
60	17.7	120	135.3
60	17.7	110	133
60	17.7	107.5	133
60	17.7	105	132.9
60	17.7	102.5	133.4
60	17.7	100	134
60	17.7	80	142.2

CYCLE #5, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	19.2	179.6	179
80	19.2	160	174.8
80	19.2	150	172.2
80	19.2	145	171.8
80	19.2	140	171.3
80	19.2	135	171.6
80	19.2	130	173.2

CYCLE #5, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	18.3	156.1	155.6
70	18.3	140	151.4
70	18.3	125	148.5
70	18.3	120	147.6
70	18.3	115	148.6

CYCLE #5, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	16.2	109.6	109.1
50	16.2	90	104.6
50	16.2	85	103.5
50	16.2	80	102.5
50	16.2	75	103.3
50	16.2	70	105.5

CYCLE #5, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	17.3	133	132.6
60	17.3	120	129.3
60	17.3	110	126.6
60	17.3	105	126
60	17.3	100	125.1
60	17.3	97.5	124.4
60	17.3	95	125.1

CYCLE #5, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	15.1	86.7	86.4
40	15.1	70	83.4
40	15.1	65	81.6
40	15.1	62.5	81
40	15.1	60	80.7
40	15.1	57.5	80.8
40	15.1	55	82.2

APPENDIX G. CONVENTIONAL CALIBRATION STRATEGY: UNDERSIZING - NO LEARNING

CYCLE #1(Raw Data)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	100	40	40	24	67.5	12.4	→	120.9	18.5
2	100	50	20	40	115.4	15.2		149.7	18.6
3	100	60	30	42	121.5	15.5		187.6	19.9
4	100	70	50	35	100.3	14.4		245.8	21.9
5	100	80	10	72	214	19.2	→	242.3	22.3

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	120.9	48	5803	5803	2304	2304		0.33	
2	50	145.9	149.7	61	9132	14935	3721	6025		0.33	
3	60	176.7	187.6	74	13882	28817	5476	11501		0.32	
4	70	207.8	245.8	87	21385	50202	7569	19070		0.28	
5	80	239	242.3	100	24230	74432	10000	29070	2.56	0.33	0.317

CYCLE #2 (Raw Data)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
2	100	50	40	30	91	13.9	→	160.3	19.2
1	100	40	10	36	110.2	14.9		115.7	16.6
3	100	60	20	48	149.1	16.7		184.6	19.5
5	100	80	50	40	123.1	15.6		305.1	22.3
4	100	70	30	49	152.4	16.9	→	227.4	20.6

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	155.7	160.3	61	9778	9778	3721	3721		0.31	
1	40	123.1	115.7	48	5554	15332	2304	6025		0.35	
3	60	188.5	184.6	74	13660	28992	5476	11501		0.33	
5	80	255	305.1	100	30510	59502	10000	21501		0.26	
4	70	221.6	227.4	87	19784	79286	7569	29070	2.73	0.31	0.302

CYCLE #3 (Raw Data, 100% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	100	70	20	56	187	18.2	→	221.3	20.2
3	100	60	40	36	117.6	15.3		198.6	19.5
1	100	40	50	20	63.4	12.1		124.8	18.4
2	100	50	10	45	146.6	16.7		156	18.2
5	100	80	30	56	187	18.2	→	273.1	21.4

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	236.3	221.3	87	19253	19253	7569	7569		0.32	
3	60	201	198.6	74	14696	33949	5476	13045		0.3	
1	40	131.3	124.8	48	5990	39939	2304	15349		0.32	
2	50	166	156	61	9516	49455	3721	19070		0.32	
5	80	271.9	273.1	100	27310	76765	10000	29070	2.64	0.29	0.308

CYCLE #4 (Raw Data, 100% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	100	70	40	42	133.7	16.1	→	242.2	20.7
1	100	40	30	28	87.3	13.7		119.1	17.3
5	100	80	20	64	208	19		257.4	21.6
2	100	50	50	25	77.5	13.1		165	19.6
3	100	60	10	54	174	17.8	→	181.5	19.3

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	228.5	242.2	87	21071	21071	7569	7569		0.29	
1	40	127	119.1	48	5717	26788	2304	9873		0.34	
5	80	262.9	257.4	100	25740	52528	10000	19873		0.31	
2	50	160.5	165	61	10065	62593	3721	23594		0.3	
3	60	194.4	181.5	74	13431	76024	5476	29070	2.62	0.33	0.311

CYCLE #5 (Raw Data, 100% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
5	100	80	40	48	152.6	16.9		286.2	21.7
4	100	70	10	63	203.1	18.8		214	20.5
2	100	50	30	35	109.5	14.9		153.4	18.4
3	100	60	50	30	93.2	14		203.5	20.3
1	100	40	20	32	99.7	14.4		117.6	16.9

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	260.9	286.2	100	28620	28620	10000	10000		0.28	
4	70	226.8	214	87	18618	47238	7569	17569		0.33	
2	50	159.3	153.4	61	9357	56595	3721	21290		0.33	
3	60	192.9	203.5	74	15059	71654	5476	26766		0.29	
1	40	126	117.6	48	5645	77299	2304	29070	2.66	0.34	0.308

CYCLE #6 (Raw Data, 100% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	100	40	40	24	74.8	12.9		121.3	17.8
2	100	50	20	40	128	15.8		150.4	18
3	100	60	30	42	134.7	16.1		191	19.4
4	100	70	50	35	111.2	15		252.9	21.1
5	100	80	10	72	237.2	20		250.1	21.8

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	128	121.3	48	5822	5822	2304	2304		0.33	
2	50	161.7	150.4	61	9174	14996	3721	6025		0.33	
3	60	195.9	191	74	14134	29130	5476	11501		0.31	
4	70	230.3	252.9	87	22002	51132	7569	19070		0.28	
5	80	284.9	250.1	100	25010	76142	10000	29070	2.62	0.32	0.311

APPENDIX H. NORMALIZATION CALIBRATION STRATEGY: UNDERSIZING - NO LEARNING

CYCLE #1 (Raw Data, 100% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	100	40	40	24	87.5	12.4	→	120.9	18.5
2	100	50	20	40	118.4	15.2		148.7	18.8
3	100	60	30	42	121.5	15.5		187.6	19.9
4	100	70	50	35	100.3	14.4		245.8	21.9
5	100	80	10	72	214	19.2	→	242.3	22.3

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	118.4	120.9	112.8	48	5805	5805	2304	2304		0.33	
2	50	146.9	148.7	142.5	61	9083	14888	3721	6025		0.33	
3	60	176.7	187.6	172.8	74	12787	28855	5476	11501		0.32	
4	70	207.8	245.8	204.4	87	17783	44666	7569	19070		0.28	
5	80	239	242.3	236.4	100	23640	68306	10000	29070	2.35	0.33	0.317

CYCLE #2 (Normalized Data, 125% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
2	100	50	40	30	88.6	13.4	→	155.3	19.5
1	100	40	10	36	101.2	14.5		115.1	17.1
3	100	60	20	48	138.9	16.2		181.5	19.8
5	100	80	50	40	113	15.1		314	23.4
4	100	70	30	49	138.9	16.3	→	224.6	21.1

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	142.9	155.3	142.4	61	8686	8686	3721	3721		0.32	
1	40	113	115.1	112.5	48	5400	14086	2304	6025		0.36	
3	60	173	181.5	172.9	74	12795	26881	5476	11501		0.33	
5	80	234.1	314	236.8	100	23680	50561	10000	21501		0.25	
4	70	203.4	224.6	204.2	87	17765	68326	7569	29070	2.36	0.31	0.303

CYCLE #3 (Normalized Data, 100% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	100	70	20	56	160.9	17.2	→	216.1	20.2
3	100	60	40	36	101.2	14.5		192.6	20.4
1	100	40	50	20	54.6	11.4		122.8	19.6
2	100	50	10	45	127.9	15.8		145.8	18.4
5	100	80	30	56	160.9	17.2	→	282.5	22.3

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	203.4	216.1	204.3	87	17774	17774	7569	7569		0.32	
3	60	173	192.6	173	74	12802	30576	5476	13045		0.31	
1	40	113	122.8	112.7	48	5410	35986	2304	15349		0.33	
2	50	142.9	145.8	142.4	61	8686	44672	3721	19070		0.34	
5	80	234.1	282.5	236.3	100	23630	68302	10000	29070	2.35	0.3	0.319

CYCLE #4 (Normalized Data, 100% DSIPTK, With Underestimation)

Proj Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	100	70	40	42	119	15.4	→	233.8	21.4
1	100	40	30	28	77.7	13.1		119.7	18
5	100	80	20	64	186.2	18.2		250.6	22.2
2	100	50	50	25	69	12.5		159.5	20.4
3	100	60	10	54	154.9	17	→	176.9	19.8

Proj Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	203.4	233.8	204.1	87	17757	17757	7569	7569		0.3	
1	40	113	119.7	112.7	48	5410	23167	2304	9873		0.33	
5	80	234.1	250.6	236.3	100	23630	46797	10000	19873		0.32	
2	50	142.9	159.5	142.3	61	8680	55477	3721	23594		0.31	
3	60	173	176.9	172.9	74	12795	68272	5476	29070	2.35	0.34	0.319

CYCLE #5 (Normalized Data, 100% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
5	100	80	40	48	138.9	16.2	⟶	284.6	22.5
4	100	70	10	63	182.1	18.1		208.7	21.2
2	100	50	30	35	98.3	14.3		152	19
3	100	60	50	30	83.6	13.4		198.6	21.2
1	100	40	20	32	89.4	13.8	⟶	118	17.5

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	234.1	284.6	236.6	100	23660	23660	10000	10000		0.28	
4	70	203.4	208.7	204.3	87	17774	41434	7569	17569		0.34	
2	50	142.9	152	142.5	61	8693	50127	3721	21290		0.33	
3	60	173	198.6	172.8	74	12787	62914	5476	26766		0.3	
1	40	113	118	112.5	48	5400	68314	2304	29070	2.35	0.34	0.312

CYCLE #6 (Normalized Data, 100% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	100	40	40	24	66.1	12.3	⟶	120.7	18.3
2	100	50	20	40	113	15.1		148.5	18.2
3	100	60	30	42	119	15.4		187.3	19.4
4	100	70	50	35	98.3	14.3		245.9	21.4
5	100	80	10	72	209.5	19.1	⟶	241.5	21.3

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	113	120.7	*	48	*	*	2304	2304		0.33	
2	50	142.9	148.5	*	61	*	*	3721	6025		0.34	
3	60	173	187.3	*	74	*	*	5476	11501		0.32	
4	70	203.4	245.9	*	87	*	*	7569	19070		0.28	
5	80	234.1	241.5	*	100	*	*	10000	29070	*	0.33	0.318

APPENDIX I. NORMALIZATION DATA: UNDERSIZING - NO LEARNING

CYCLE #1, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18.5	120.9	120.6
40	18.5	115	115.3
40	18.5	110	114.6
40	18.5	105	113.4
40	18.5	100	112.7
40	18.5	95	112.6
40	18.5	90	112.7
40	18.5	85	113.3
40	18.5	80	115.4

CYCLE #1, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	18.6	149.7	149.4
50	18.6	145	146.2
50	18.6	140	145.9
50	18.6	135	143.8
50	18.6	130	143.1
50	18.6	125	142.9
50	18.6	120	142.6
50	18.6	118	142.5
50	18.6	115	142.6

CYCLE #1, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.9	187.6	187.3
60	19.9	180	180.1
60	19.9	170	176.9
60	19.9	160	174.4
60	19.9	155	173.2
60	19.9	150	173
60	19.9	145	172.8
60	19.9	140	173.4
60	19.9	135	174.3

CYCLE #1, PROJECT #4

KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	21.9	245.8	243.7
70	21.9	235	234.1
70	21.9	220	219.6
70	21.9	210	212.3
70	21.9	200	207.9
70	21.9	190	205.3
70	21.9	185	204.4
70	21.9	175	204.7
70	21.9	170	205.3

CYCLE #1, PROJECT #5

KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	22.3	242.3	246.7
80	22.3	235	242
80	22.3	225	238.8
80	22.3	220	237.6
80	22.3	215	236.6
80	22.3	210	236.5
80	22.3	205	236.4
80	22.3	200	237.2
80	22.3	195	238.2

CYCLE #2, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	19.5	155.3	159.8
50	19.5	150	149.5
50	19.5	145	146.3
50	19.5	140	145.4
50	19.5	130	143.1
50	19.5	120	142.4
50	19.5	115	142.6
50	19.5	110	143.1
50	19.5	100	146.8

CYCLE #2, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	17.1	115.1	115.4
40	17.1	105	113.9
40	17.1	100	112.9
40	17.1	95	112.5
40	17.1	93	112.8
40	17.1	90	112.7
40	17.1	85	113.1

CYCLE #2, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.8	181.5	184.1
60	19.8	175	178.6
60	19.8	165	175.4
60	19.8	155	173.5
60	19.8	145	173.3
60	19.8	140	172.9
60	19.8	135	174.1
60	19.8	130	175.1

CYCLE #2, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	23.4	314	297.1
80	23.4	285	282.9
80	23.4	265	264.7
80	23.4	245	247.3
80	23.4	225	238.8
80	23.4	215	237.6
80	23.4	205	236.8
80	23.4	200	237.2
80	23.4	195	238.2

CYCLE #2, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	21.1	224.6	226.9
70	21.1	215	214.5
70	21.1	205	211.1
70	21.1	195	206.8
70	21.1	185	205.2
70	21.1	180	204.5
70	21.1	175	204.2
70	21.1	170	204.7
70	21.1	165	205.4

CYCLE #3, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	20.2	216.1	220.6
70	20.2	210	212.3
70	20.2	200	208.7
70	20.2	190	206.2
70	20.2	180	204.4
70	20.2	178	204.3
70	20.2	175	204.4
70	20.2	170	204.7
70	20.2	165	205.1

CYCLE #3, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	20.4	192.6	198.1
60	20.4	175	178.6
60	20.4	165	175.4
60	20.4	155	173.5
60	20.4	150	173.1
60	20.4	145	173.3
60	20.4	140	173.1
60	20.4	135	174.1
60	20.4	130	175.1

CYCLE #3, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	19.6	122.8	124.5
40	19.6	115	115.3
40	19.6	105	113.5
40	19.6	100	112.9
40	19.6	97	112.8
40	19.6	95	112.7
40	19.6	90	112.7
40	19.6	85	113.5
40	19.6	80	114.8

CYCLE #3, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	18.4	145.8	155.9
50	18.4	140	145.9
50	18.4	130	143.3
50	18.4	125	142.8
50	18.4	120	142.7
50	18.4	115	142.4
50	18.4	110	142.9
50	18.4	105	143.7
50	18.4	100	145.5

CYCLE #3, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	22.3	262.5	262.3
80	22.3	250	249.3
80	22.3	230	241
80	22.3	215	237.2
80	22.3	210	236.9
80	22.3	205	236.3
80	22.3	200	236.8
80	22.3	195	237.2
80	22.3	190	238.5

CYCLE #4, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	21.4	233.8	233.1
70	21.4	210	212.2
70	21.4	200	208
70	21.4	190	205.6
70	21.4	180	204.4
70	21.4	175	204.1
70	21.4	170	205.2
70	21.4	160	206.3
70	21.4	155	209.1

CYCLE #4, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18	119.7	119.6
40	18	110	115.1
40	18	105	113.6
40	18	100	113
40	18	95	112.7
40	18	90	112.7
40	18	85	113.2
40	18	80	114.8
40	18	75	118

CYCLE #4, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	22.2	250.6	249.8
80	22.2	240	245.5
80	22.2	220	237.7
80	22.2	215	236.7
80	22.2	210	236.3
80	22.2	205	236.4
80	22.2	200	237.3
80	22.2	195	238.2

CYCLE #4, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	20.4	159.5	159
50	20.4	140	145.3
50	20.4	130	142.9
50	20.4	125	142.3
50	20.4	120	142.7
50	20.4	115	143.4

CYCLE #4, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.8	176.9	176.7
60	19.8	160	174.4
60	19.8	155	173.8
60	19.8	150	173.1
60	19.8	145	172.9
60	19.8	140	173.5
60	19.8	135	174
60	19.8	130	175.4

CYCLE #5, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	22.5	284.6	282.6
80	22.5	260	259.3
80	22.5	240	245.5
80	22.5	220	237.5
80	22.5	215	237
80	22.5	210	236.6
80	22.5	205	236.8
80	22.5	200	237.1

CYCLE #5, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	21.2	208.7	211.8
70	21.2	200	208
70	21.2	190	205.7
70	21.2	180	204.6
70	21.2	175	204.3
70	21.2	170	205
70	21.2	165	205.7

CYCLE #5, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	19	152	151.5
50	19	140	145.4
50	19	130	143.2
50	19	125	142.5
50	19	120	142.6
50	19	115	142.5
50	19	110	143.1
50	19	105	144.5

CYCLE #5, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	21.2	198.6	198
60	21.2	180	180.2
60	21.2	160	173.8
60	21.2	155	173.3
60	21.2	150	172.8
60	21.2	145	173.6
60	21.2	140	174.4
60	21.2	135	175

CYCLE #5, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	17.5	118	117.7
40	17.5	110	114.7
40	17.5	105	113.5
40	17.5	100	113
40	17.5	95	112.5
40	17.5	90	112.6
40	17.5	85	113
40	17.5	80	114.4
40	17.5	70	119.7

APPENDIX J. CONVENTIONAL CALIBRATION STRATEGY: UNDERSIZING - 75% DSIPTK

CYCLE #1(Raw Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1	75	40	40	24	67.5	12.4	144.7	20.2
2	75	50	20	40	115.4	15.2	181.2	20.9
3	75	60	30	42	121.5	15.5	221.8	22.4
4	75	70	50	35	100.3	14.4	307.8	24.9
5	75	80	10	72	214	19.2	289.8	25.1

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	144.7	48	6946	6946	2304	2304		0.28	
2	50	145.9	181.2	61	11053	17999	3721	6025		0.28	
3	60	176.7	221.8	74	16413	34412	5476	11501		0.27	
4	70	207.8	307.8	87	26779	61191	7569	19070		0.23	
5	80	239	289.8	100	28980	90171	10000	29070	3.1	0.28	0.262

CYCLE #2 (Raw Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
2	75	50	40	30	110.2	14.9	187.4	19.9
1	75	40	10	36	133.5	16.1	138.1	17.6
3	75	60	20	48	180.6	18	220.7	20.8
5	75	80	50	40	149.1	16.7	370.4	23.9
4	75	70	30	49	184.5	18.2	272.7	22.2

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	188.5	187.4	61	11431	11431	3721	3721		0.27	
1	40	149.1	138.1	48	6629	18060	2304	6025		0.29	
3	60	228.3	220.7	74	16332	34392	5476	11501		0.27	
5	80	308.7	370.4	100	37040	71432	10000	21501		0.22	
4	70	268.4	272.7	87	23725	95157	7569	29070	3.27	0.26	0.252

CYCLE #3 (Raw Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	75	70	20	56	223.9	19.5	265.8	21.8
3	75	60	40	36	140.8	16.4	235.4	20.7
1	75	40	50	20	76	13	148.1	19.2
2	75	50	10	45	178	17.9	183.1	19.3
5	75	80	30	56	223.9	19.5	323.5	23.1

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	283.1	265.8	87	23125	23125	7569	7569		0.26	
3	60	240.8	235.4	74	17420	40545	5476	13045		0.25	
1	40	157.3	148.1	48	7109	47654	2304	15349		0.27	
2	50	198.8	183.1	61	11169	58823	3721	19070		0.27	
5	80	325.7	323.5	100	32350	91173	10000	29070	3.14	0.25	0.26

CYCLE #4 (Raw Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	75	70	40	42	159	17.2	284.8	22.2
1	75	40	30	28	103.9	14.6	143	18.3
5	75	80	20	64	247.4	20.3	309.7	23.5
2	75	50	50	25	92.2	13.9	192.2	20.5
3	75	60	10	54	207	19	216	20.8

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	271.8	284.8	87	24778	24778	7569	7569		0.25	
1	40	151	143	48	6864	31642	2304	9873		0.28	
5	80	312.7	309.7	100	30970	62612	10000	19873		0.26	
2	50	190.9	192.2	61	11724	74336	3721	23594		0.26	
3	60	231.2	216	74	15984	90320	5476	29070	3.11	0.28	0.262

CYCLE #5 (Raw Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
5	75	80	40	48	181.2	18	→	342.7	23
4	75	70	10	63	241	20.1		264.3	20.8
2	75	50	30	35	130	15.9		184.6	18.2
3	75	60	50	30	110.6	14.9		243.4	20.2
1	75	40	20	32	118.3	15.3	→	149.1	16.7

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	309.7	342.7	100	34270	34270	10000	10000		0.23	
4	70	269.2	264.3	87	22994	57264	7569	17569		0.26	
2	50	189.1	184.6	61	11261	68525	3721	21290		0.27	
3	60	229	243.4	74	18012	86537	5476	26766		0.25	
1	40	149.6	149.1	48	7157	93694	2304	29070	3.22	0.27	0.253

CYCLE #6 (Raw Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	75	40	40	24	90.6	13.9	→	145.7	18.6
2	75	50	20	40	154.9	17		178.7	19.1
3	75	60	30	42	163	17.3		227.6	20.6
4	75	70	50	35	134.6	16.1		298.4	22.3
5	75	80	10	72	287.1	21.5	→	300.9	23.7

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	154.9	145.7	48	6994	6994	2304	2304		0.27	
2	50	195.8	178.7	61	10901	17895	3721	6025		0.28	
3	60	237.1	227.6	74	16842	34737	5476	11501		0.26	
4	70	278.7	298.4	87	25961	60698	7569	19070		0.23	
5	80	320.7	300.9	100	30090	90788	10000	29070	3.12	0.27	0.261

APPENDIX K. NORMALIZATION CALIBRATION STRATEGY: UNDERSIZING - 75% DSIPTK

CYCLE #1 (Raw Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	75	40	40	24	67.5	12.4		144.7	20.2
2	75	50	20	40	115.4	15.2		181.2	20.9
3	75	60	30	42	121.5	15.5		221.8	22.4
4	75	70	50	35	100.3	14.4		307.8	24.9
5	75	80	10	72	214	19.2		289.8	25.1

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	144.7	137.2	48	6586	6586	2304	2304		0.28	
2	50	145.9	181.2	174.5	61	10645	17231	3721	6025		0.28	
3	60	176.7	221.8	212.5	74	15725	32956	5476	11501		0.27	
4	70	207.8	307.8	251.4	87	21872	54828	7569	19070		0.23	
5	80	239	289.8	289	100	28900	83728	10000	29070	2.88	0.28	0.262

CYCLE #2 (Normalized Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
2	75	50	40	30	102.4	14.5		188.7	20.6
1	75	40	10	36	124	15.6		137.6	18.1
3	75	60	20	48	167.8	17.5		220	21.3
5	75	80	50	40	138.5	16.3		370.7	24.6
4	75	70	30	49	171.4	17.7		275	22.8

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	175.1	188.7	174.4	61	10638	10638	3721	3721		0.26	
1	40	138.5	137.6	137.1	48	6581	17219	2304	6025		0.29	
3	60	212.1	220	212.7	74	15740	32959	5476	11501		0.27	
5	80	286.8	370.7	294.6	100	29460	62419	10000	21501		0.22	
4	70	249.3	275	252.4	87	21959	84378	7569	29070	2.9	0.25	0.252

CYCLE #3 (Normalized Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	75	70	20	56	198.8	18.7		264.9	22.8
3	75	60	40	36	124.9	15.7		235.8	21.7
1	75	40	50	20	67.4	12.4		150	20.4
2	75	50	10	45	157.9	17.1		175.3	19.7
5	75	80	30	56	198.6	18.7		324.9	24.1

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	251	264.9	252.4	87	21959	21959	7569	7569		0.26	
3	60	213.5	235.8	212.7	74	15740	37699	5476	13045		0.25	
1	40	139.5	150	137.2	48	6586	44285	2304	15349		0.27	
2	50	176.3	175.3	174.2	61	10626	54911	3721	19070		0.29	
5	80	288.8	324.9	295.1	100	29510	84421	10000	29070	2.9	0.25	0.261

CYCLE #4 (Normalized Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
4	75	70	40	42	146.8	16.6		285.2	22.7
1	75	40	30	28	95.9	14.2		142.4	18.8
5	75	80	20	64	228.5	19.7		312	24.2
2	75	50	50	25	85.2	13.5		194.2	21.3
3	75	60	10	54	191.2	18.4		214.5	21.4

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	251	285.2	252.3	87	21950	21950	7569	7569		0.25	
1	40	139.5	142.4	137.3	48	6590	28540	2304	9873		0.28	
5	80	288.8	312	294.6	100	29460	58000	10000	19873		0.26	
2	50	176.3	194.2	174.3	61	10632	68632	3721	23594		0.26	
3	60	213.5	214.5	212.4	74	15718	84350	5476	29070	2.9	0.28	0.261

CYCLE #5 (Normalized Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
5	75	80	40	48	168.9	17.6	339.2	23.9
4	75	70	10	63	224.8	19.6	256.7	23.1
2	75	50	30	35	121.2	15.5	183.1	20.2
3	75	60	50	30	103.1	14.6	241.5	22.2
1	75	40	20	32	110.4	14.9	139.8	18.4

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	288.8	339.2	296	100	29600	29600	10000	10000		0.24	
4	70	251	256.7	252.9	87	22002	51602	7569	17569		0.27	
2	50	176.3	183.1	174.4	61	10638	62240	3721	21290		0.27	
3	60	213.5	241.5	212.6	74	15732	77972	5476	26766		0.25	
1	40	139.5	139.8	137.1	48	6581	84553	2304	29070	2.91	0.29	0.259

CYCLE #6 (Normalized Data, 75% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1	75	40	40	24	81.9	13.3	146.2	19.4
2	75	50	20	40	140	16.3	178.5	19.8
3	75	60	30	42	147.3	16.7	227.8	21.5
4	75	70	50	35	121.7	15.5	294.7	23.1
5	75	80	10	72	259.5	20.7	301.7	24.6

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	140	146.2	*	48	*	*	2304	2304	*	0.27	
2	50	176.9	178.5	*	61	*	*	3721	6025	*	0.28	
3	60	214.3	227.8	*	74	*	*	5476	11501	*	0.26	
4	70	251.9	294.7	*	87	*	*	7569	19070	*	0.24	
5	80	288.8	301.7	*	100	*	*	10000	29070	*	0.27	0.261

APPENDIX L. NORMALIZATION DATA: UNDERSIZING - 75% DSIPTK

CYCLE #1, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	20.2	144.7	144.6
40	20.2	135	137.5
40	20.2	130	137.2
40	20.2	125	137.4
40	20.2	120	138.9

CYCLE #1, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	20.9	181.2	180.9
50	20.9	170	174.6
50	20.9	165	174.5
50	20.9	160	174.8

CYCLE #1, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	22.4	221.8	221.1
60	22.4	210	212.5
60	22.4	208	212.5
60	22.4	205	212.5
60	22.4	200	212.8

CYCLE #1, PROJECT #4

KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	24.9	307.8	296.1
70	24.9	300	292.1
70	24.9	290	285.8
70	24.9	280	278.2
70	24.9	270	268.9
70	24.9	260	259.4
70	24.9	250	251.4
70	24.9	245	251.4
70	24.9	240	252

CYCLE #1, PROJECT #5

KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	25.1	289.8	294.2
80	25.1	265	298.7
80	25.1	255	300.4
80	25.1	245	298.4
80	25.1	230	290.4
80	25.1	225	289
80	25.1	220	289.1
80	25.1	215	290.9
80	25.1	210	292.6

CYCLE #2, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	20.6	188.7	188.3
50	20.6	180	179.6
50	20.6	170	174.6
50	20.6	165	174.5
50	20.6	163	174.4
50	20.6	160	174.5

CYCLE #2, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18.1	137.6	137.5
40	18.1	135	137.5
40	18.1	130	137.1
40	18.1	128	137.2
40	18.1	125	137.1
40	18.1	120	137.5

CYCLE #2, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	21.3	220	219.8
60	21.3	205	212.8
60	21.3	200	212.7
60	21.3	195	212.9
60	21.3	190	213.8
60	21.3	180	217

CYCLE #2, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	24.6	370.7	354
80	24.6	350	342.6
80	24.6	330	327.7
80	24.6	310	309.2
80	24.6	290	295.3
80	24.6	285	295
80	24.6	280	294.6
80	24.6	270	296.8

CYCLE #2, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	22.8	275	273.9
70	22.8	265	264.4
70	22.8	255	254.4
70	22.8	245	252.8
70	22.8	240	252.7
70	22.8	235	252.4
70	22.8	230	253.6
70	22.8	225	255.4

CYCLE #3, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	22.8	264.9	264.3
70	22.8	245	252.8
70	22.8	240	252.7
70	22.8	235	252.4
70	22.8	230	253.6
70	22.8	225	255.4
70	22.8	220	256.7

CYCLE #3, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	21.7	235.8	234.7
60	21.7	220	219.5
60	21.7	210	212.8
60	21.7	205	212.8
60	21.7	200	212.7
60	21.7	195	213
60	21.7	190	214.2
60	21.7	180	216.8

CYCLE #3, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	20.4	150	149.6
40	20.4	135	137.5
40	20.4	130	137.2
40	20.4	125	137.7
40	20.4	120	139.1

CYCLE #3, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	19.7	175.3	174.9
50	19.7	170	174.5
50	19.7	165	174.2
50	19.7	160	174.4
50	19.7	155	175
50	19.7	150	176.7

CYCLE #3, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	24.1	324.9	323.7
80	24.1	300	299.5
80	24.1	285	295.5
80	24.1	280	295.1
80	24.1	275	295.5
80	24.1	270	297.1
80	24.1	265	298.5
80	24.1	260	299.7

CYCLE #4, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	22.7	285.2	279.8
70	22.7	260	259.6
70	22.7	245	252.4
70	22.7	240	252.3
70	22.7	235	252.6
70	22.7	230	253.8
70	22.7	225	255.7
70	22.7	220	257.2

CYCLE #4, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18.8	142.4	144.3
40	18.8	135	137.3
40	18.8	132.5	137.4
40	18.8	130	137.3
40	18.8	125	137.4
40	18.8	120	138.3

CYCLE #4, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	24.2	312	311.1
80	24.2	290	295.2
80	24.2	285	295
80	24.2	280	294.6
80	24.2	275	295.7
80	24.2	270	296.9

CYCLE #4, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	21.3	194.2	191.1
50	21.3	180	179.6
50	21.3	175	174.6
50	21.3	170	174.3
50	21.3	165	174.5
50	21.3	160	174.8
50	21.3	155	176.4
50	21.3	150	178.2

CYCLE #4, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	21.4	214.5	215.5
60	21.4	210	212.8
60	21.4	207.5	212.8
60	21.4	205	212.4
60	21.4	200	212.7
60	21.4	195	213
60	21.4	190	214.2
60	21.4	185	216.1
60	21.4	180	216.8

CYCLE #5, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	23.9	339.2	337.6
80	23.9	320	319
80	23.9	300	299.7
80	23.9	285	296
80	23.9	282.5	296.2
80	23.9	280	296.3
80	23.9	275	296.4
80	23.9	270	297.4
80	23.9	260	300

CYCLE #5, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	23.1	256.7	256.9
70	23.1	240	253.2
70	23.1	235	252.9
70	23.1	230	253.6
70	23.1	225	255.2
70	23.1	220	256.4

CYCLE #5, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	20.2	183.1	182.6
50	20.2	170	174.9
50	20.2	165	174.7
50	20.2	160	174.4
50	20.2	155	175
50	20.2	150	176.8

CYCLE #5, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	22.2	241.5	239.4
60	22.2	220	219.4
60	22.2	205	212.8
60	22.2	200	212.6
60	22.2	195	213
60	22.2	190	214.2
60	22.2	185	215.7
60	22.2	180	216.9

CYCLE #5, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	18.4	139.8	138.8
40	16.3	130	137.1
40	16.3	127.5	137.2
40	16.3	125	137.1
40	16.3	120	137.5
40	16.3	115	139
40	16.3	110	139.8

APPENDIX M. CONVENTIONAL CALIBRATION STRATEGY: UNDERSIZING - 125% DSIPTK

CYCLE #1(Raw Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1	125	40	40	24	67.5	12.4	109.5	17.1
2	125	50	20	40	115.4	15.2	138.2	17.4
3	125	60	30	42	121.5	15.5	169	18.4
4	125	70	50	35	100.3	14.4	230.9	20.3
5	125	80	10	72	214	19.2	224.1	20.5

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	109.5	48	5256	5256	2304	2304		0.37	
2	50	145.9	138.2	61	8430	13686	3721	6025		0.36	
3	60	176.7	169	74	12506	26192	5476	11501		0.36	
4	70	207.8	230.9	87	20088	46280	7569	19070		0.3	
5	80	239	224.1	100	22410	68690	10000	29070	2.36	0.36	0.344

CYCLE #2 (Raw Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
2	125	50	40	30	83.9	13.5	140.2	18.1
1	125	40	10	36	101.6	14.5	108.5	16.3
3	125	60	20	48	137.5	16.2	164.2	18.3
5	125	80	50	40	113.5	15.1	280.7	21.2
4	125	70	30	49	140.5	16.4	202.4	19.5

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	143.5	140.2	61	8552	8552	3721	3721		0.36	
1	40	113.5	108.5	48	5208	13760	2304	6025		0.37	
3	60	173.8	164.2	74	12151	25911	5476	11501		0.37	
5	80	235	280.7	100	28070	53981	10000	21501		0.29	
4	70	204.3	202.4	87	17609	71590	7569	29070	2.46	0.35	0.335

CYCLE #3 (Raw Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	125	70	20	56	168.5	17.5	201	19.3
3	125	60	40	36	105.9	14.7	175.8	18.5
1	125	40	50	20	57.2	11.6	112.7	17.7
2	125	50	10	45	133.9	16.1	142.5	17.6
5	125	80	30	56	168.5	17.5	240	20.2

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	213	201	87	17487	17487	7569	7569		0.35	
3	60	181.1	175.8	74	13009	30496	5476	13045		0.34	
1	40	118.3	112.7	74	8340	38836	5476	18521		0.35	
2	50	149.6	142.5	61	8693	47529	3721	22242		0.35	
5	80	245	240	100	24000	71529	10000	32242	2.22	0.33	0.344

CYCLE #4 (Raw Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	125	70	40	42	112.4	15	218	20.3
1	125	40	30	28	73.4	12.8	104.6	16.9
5	125	80	20	64	174.9	17.8	228.4	20.9
2	125	50	50	25	65.2	12.2	146.7	19.4
3	125	60	10	54	146.3	16.6	157.6	18.5

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	192.2	218	87	18966	18966	7569	7569		0.32	
1	40	106.8	104.6	48	5021	23987	2304	9873		0.38	
5	80	221.1	228.4	74	16902	40889	5476	15349		0.35	
2	50	135	146.7	61	8949	49838	3721	19070		0.34	
3	60	163.5	157.6	74	11662	61500	5476	24546	2.51	0.38	0.351

CYCLE #5 (Raw Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
5	125	80	40	48	146.2	16.6	→	256.7	20.2
4	125	70	10	63	194.5	18.5		206.3	19.8
2	125	50	30	35	104.9	14.6		145.6	17.5
3	125	60	50	30	89.3	13.8		183.9	19
1	125	40	20	32	95.5	14.1	→	115.8	16.6

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	250	256.7	100	25670	25670	10000	10000		0.31	
4	70	217.3	206.3	87	17948	43618	7569	17569		0.34	
2	50	152.6	145.6	74	10774	54392	5476	23045		0.34	
3	60	184.8	183.9	74	13609	68001	5476	28521		0.33	
1	40	120.7	115.8	48	5558	73559	2304	30825	2.39	0.35	0.33

CYCLE #6 (Raw Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	125	40	40	24	67.2	12.4	→	109.3	17.2
2	125	50	20	40	115	15.2		137.7	17.4
3	125	60	30	42	121	15.5		168.8	18.4
4	125	70	50	35	99.9	14.4		231.3	20.4
5	125	80	10	72	213.1	19.2	→	223	20.5

Proj.Serial	KDSI (act)	MM (est)	MM(act)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115	109.3	48	5246	5246	2304	2304		0.37	
2	50	145.3	137.7	61	8400	13646	3721	6025		0.36	
3	60	176	168.8	74	12491	26137	5476	11501		0.36	
4	70	206.9	231.3	87	20123	46260	7569	19070		0.3	
5	80	238	223	100	22300	68560	10000	29070	2.36	0.36	0.345

APPENDIX N. NORMALIZATION CALIBRATION STRATEGY: UNDERSIZING - 125% DSIPTK

CYCLE #1 (Raw Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
1	125	40	40	24	67.5	12.4	109.5	17.1
2	125	50	20	40	115.4	15.2	138.2	17.4
3	125	60	30	42	121.5	15.5	169	18.4
4	125	70	50	35	100.3	14.4	230.9	20.3
5	125	80	10	72	214	19.2	224.1	20.5

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	115.4	109.5	100.6	48	4829	4829	2304	2304		0.37	
2	50	145.9	138.2	125	61	7625	12454	3721	6025		0.36	
3	60	176.7	169	151.9	74	11241	23695	5476	11501		0.36	
4	70	207.8	230.9	180.2	87	15677	39372	7569	19070		0.3	
5	80	239	224.1	208.2	100	20820	60192	10000	29070	2.07	0.36	0.344

CYCLE #2 (Normalized Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
2	125	50	40	30	73.6	12.8	140.1	18.9
1	125	40	10	36	89.1	13.8	100.1	16.3
3	125	60	20	48	120.6	15.4	164.1	19.1
5	125	80	50	40	99.6	14.4	273	22.2
4	125	70	30	49	123.2	15.6	199.3	20.1

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
2	50	175.1	140.1	125.3	61	7643	7643	3721	3721		0.36	
1	40	138.5	100.1	98.5	48	4728	12371	2304	6025		0.4	
3	60	212.1	164.1	152.3	74	11270	23641	5476	11501		0.37	
5	80	286.8	273	208.6	100	20860	44501	10000	21501		0.29	
4	70	249.3	199.3	180	87	15660	60161	7569	29070	2.07	0.35	0.342

CYCLE #3 (Normalized Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	125	70	20	56	141.8	16.4	191.9	19.1
3	125	60	40	36	89.1	13.8	172.5	19.7
1	125	40	50	20	48.1	10.9	109	19.1
2	125	50	10	45	112.7	15.1	128.7	17.7
5	125	80	30	56	141.8	16.4	234.3	21

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	179.2	191.9	179.9	87	15651	15651	7569	7569		0.36	
3	60	152.4	172.5	152.4	74	11278	26929	5476	13045		0.35	
1	40	99.6	109	99.6	74	7370	34299	5476	18521		0.37	
2	50	125.9	128.7	124.9	61	7619	41918	3721	22242		0.39	
5	80	206.2	234.2	208.1	100	20810	62728	10000	32242	1.95	0.34	0.359

CYCLE #4 (Normalized Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)	MM (act)	TDEV (act)
4	125	70	40	42	98.7	14.3	205.8	20.8
1	125	40	30	28	64.5	12.2	105.2	17.6
5	125	80	20	64	153.6	16.9	219.4	21.2
2	125	50	50	25	57.3	11.6	138.7	20.1
3	125	60	10	54	128.5	15.8	154.8	18.9

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
4	70	168.8	205.8	180.2	87	15677	15677	7569	7569		0.34	
1	40	93.8	105.2	99	48	4752	20429	2304	9873		0.38	
5	80	194.2	219.4	208	74	15392	35821	5476	15349		0.36	
2	50	118.6	138.7	125.9	61	7680	43501	3721	19070		0.36	
3	60	143.6	154.8	152.1	74	11255	54756	5476	24546	2.23	0.39	0.364

CYCLE #5 (Normalized Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
5	125	80	40	48	129.9	15.9		257.3	21
4	125	70	10	63	172.8	17.7		186.7	19.6
2	125	50	30	35	93.2	14		134.8	17.8
3	125	60	50	30	79.3	13.2		184.5	20.1
1	125	40	20	32	84.9	13.5		102.8	16.3

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
5	80	222.1	257.3	208.2	100	20820	20820	10000	10000		0.31	
4	70	193	186.7	179.7	87	15634	36454	7569	17569		0.37	
2	50	135.6	134.8	125.2	74	9265	45719	5476	23045		0.37	
3	60	164.2	184.5	152.6	74	11292	57011	5476	28521		0.33	
1	40	107.3	102.8	98.5	48	4728	61739	2304	30825	2	0.39	0.346

CYCLE #6 (Normalized Data, 125% DSIPTK, With Underestimation)

Proj.Serial	DSIPTK (%)	KDSI (act)	Under (%)	KDSI (est)	MM (est)	TDEV (est)		MM (act)	TDEV (act)
1	125	40	40	24	56.3	11.6		106.8	18.3
2	125	50	20	40	96.2	14.2		133.6	18.2
3	125	60	30	42	101.3	14.5		165.6	19.4
4	125	70	50	35	83.6	13.4		217.7	21.4
5	125	80	10	72	178.3	17.9		212.2	21.3

Proj.Serial	KDSI (act)	MM (est)	MM(act)	MM(norm)	Q	MM(act)*Q	sum MM(act)*Q	Q^2	sum Q^2	Coefficient	Productivity	Comp Prod
1	40	96.2	106.8	*	48	*	*	2304	2304		0.37	
2	50	121.6	133.6	*	61	*	*	3721	6025		0.37	
3	60	147.3	165.6	*	74	*	*	5476	11501		0.36	
4	70	173.1	217.7	*	87	*	*	7569	19070		0.32	
5	80	199.2	212.2	*	100	*	*	10000	29070	*	0.38	0.359

APPENDIX O. NORMALIZATION DATA: UNDERSIZING - 125% DSIPTK

CYCLE #1, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	17.1	109.5	109.4
40	17.1	105	104.6
40	17.1	103	102.6
40	17.1	100	101
40	17.1	98	100.6
40	17.1	95	101.3

CYCLE #1, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	17.4	138.2	137.8
50	17.4	130	129.6
50	17.4	120	128.4
50	17.4	115	127.2
50	17.4	110	125.9
50	17.4	105	125
50	17.4	100	125
50	17.4	98	125.2
50	17.4	95	125.8

CYCLE #1, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	18.4	169	168.5
60	18.4	150	155.8
60	18.4	130	152.3
60	18.4	128	152.4
60	18.4	125	151.9
60	18.4	123	152
60	18.4	120	152.6
60	18.4	115	153.6

CYCLE #1, PROJECT #4

KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	20.3	230.9	225
70	20.3	200	199.4
70	20.3	180	185.8
70	20.3	175	184.3
70	20.3	170	182.7
70	20.3	165	181.4
70	20.3	160	180.3
70	20.3	150	180.2
70	20.3	145	180.7

CYCLE #1, PROJECT #5

KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	20.5	224.1	223.5
80	20.5	190	209.4
80	20.5	180	208.3
80	20.5	178	206.2
80	20.5	175	208.3
80	20.5	170	209
80	20.5	165	209.7
80	20.5	150	214

CYCLE #2, PROJECT #2

KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	18.9	140.1	139.9
50	18.9	130	129.8
50	18.9	120	128.4
50	18.9	115	126.5
50	18.9	110	125.7
50	18.9	105	125.3
50	18.9	100	125.6
50	18.9	95	127.1

CYCLE #2, PROJECT #1

KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	16.3	100.1	100.9
40	16.3	90	100.3
40	16.3	80	98.7
40	16.3	75	98.5
40	16.3	70	100.5

CYCLE #2, PROJECT #3

KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.1	164.1	163.5
60	19.1	140	153.8
60	19.1	130	152.4
60	19.1	125	152.3
60	19.1	120	153.2
60	19.1	110	157.6

CYCLE #2, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	22.2	273	262.4
80	22.2	250	248.1
80	22.2	230	229.2
80	22.2	210	215.8
80	22.2	190	209.2
80	22.2	180	208.6
80	22.2	170	210.4

CYCLE #2, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	20.1	199.3	198.6
70	20.1	170	182.8
70	20.1	160	180.5
70	20.1	155	180
70	20.1	150	180
70	20.1	145	180.5
70	20.1	130	185.3

CYCLE #3, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	19.1	191.9	191.3
70	19.1	180	184.6
70	19.1	170	182.9
70	19.1	160	180.4
70	19.1	155	180.2
70	19.1	150	179.9
70	19.1	145	180.2
70	19.1	140	181
70	19.1	130	185.5

CYCLE #3, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	19.7	172.5	172.2
60	19.7	160	159.7
60	19.7	150	157.2
60	19.7	140	153.8
60	19.7	130	152.6
60	19.7	125	152.4
60	19.7	120	153.6

CYCLE #3, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	19.1	109	108.6
40	19.1	100	101.7
40	19.1	90	100
40	19.1	85	99.6
40	19.1	80	99.8
40	19.1	75	101.1
40	19.1	70	103.3

CYCLE #3, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	17.7	128.7	129.1
50	17.7	120	128.9
50	17.7	110	126
50	17.7	105	125.1
50	17.7	100	124.9
50	17.7	95	126.1
50	17.7	90	128.2

CYCLE #3, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	21	234.3	233.9
80	21	220	219.2
80	21	200	212.1
80	21	180	208.2
80	21	178	208.1
80	21	175	208.2
80	21	170	209.3
80	21	160	213.8

CYCLE #4, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	20.8	205.8	205
70	20.8	190	189.2
70	20.8	170	182.5
70	20.8	165	181.1
70	20.8	160	180.3
70	20.8	155	180.2
70	20.8	150	180.6
70	20.8	145	181.5
70	20.8	130	184.9

CYCLE #4, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	17.6	105.2	105
40	17.6	100	101.2
40	17.6	90	100.2
40	17.6	85	99.2
40	17.6	83	99
40	17.6	80	99.2
40	17.6	75	100.1
40	17.6	70	102.1

CYCLE #4, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	21.2	219.4	218.7
80	21.2	200	212
80	21.2	190	209.4
80	21.2	185	208.7
80	21.2	180	208
80	21.2	175	208.5
80	21.2	170	209
80	21.2	160	213.1

CYCLE #4, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	20.1	138.7	138.2
50	20.1	130	130.1
50	20.1	120	127.9
50	20.1	115	126.6
50	20.1	110	125.9
50	20.1	105	126
50	20.1	100	126.7

CYCLE #4, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	18.9	154.8	156.5
60	18.9	140	153.9
60	18.9	135	153.1
60	18.9	130	152.1
60	18.9	128	152.1
60	18.9	125	152.1
60	18.9	120	153.2

CYCLE #5, PROJECT #5			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
80	21	257.3	254.4
80	21	240	239.1
80	21	220	219.2
80	21	200	212.1
80	21	190	209.6
80	21	180	208.2
80	21	177.5	208.2
80	21	175	208.2
80	21	160	213.8

CYCLE #5, PROJECT #4			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
70	19.6	186.7	186.7
70	19.6	165	181.4
70	19.6	155	180.1
70	19.6	150	179.7
70	19.6	145	180.3
70	19.6	140	181.5
70	19.6	130	186.2

CYCLE #5, PROJECT #2			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
50	17.8	134.8	134.6
50	17.8	120	128.8
50	17.8	110	125.9
50	17.8	105	125.4
50	17.8	100	125.2
50	17.8	95	126.3
50	17.8	90	128.4

CYCLE #5, PROJECT #3			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
60	20.1	184.5	182.9
60	20.1	160	159.5
60	20.1	140	153.6
60	20.1	135	152.8
60	20.1	130	152.6
60	20.1	125	152.8
60	20.1	120	153.8

CYCLE #5, PROJECT #1			
KDSI (est)	TDEV (est)	MM (est)	MM (act)
40	16.3	102.8	102.4
40	16.3	90	100.3
40	16.3	80	98.7
40	16.3	77.5	98.9
40	16.3	75	98.5
40	16.3	72.5	99.5
40	16.3	70	100.5
40	16.3	65	103.3

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